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(54) **IMAGING OPTICAL SYSTEM, AND IMAGE CAPTURE DEVICE AND CAMERA SYSTEM INCLUDING THE SAME**

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(57) **ABSTRACT**

An imaging optical system includes: a first lens group having positive power; a second lens group having negative power; a third lens group having positive power; a fourth lens group having positive power; a fifth lens group having negative power; and a sixth lens group having power. The first, second, third, fourth, fifth, and sixth lens groups are arranged in this order such that the first lens group is located closest to an object and that the sixth lens group is located closest to an image plane. An interval between each pair of lens groups that are adjacent to each other changes as at least the first, second, third, fourth, fifth, and sixth lens groups move in an optical axis direction aligned with an optical axis of the imaging optical system while the imaging optical system is zooming.

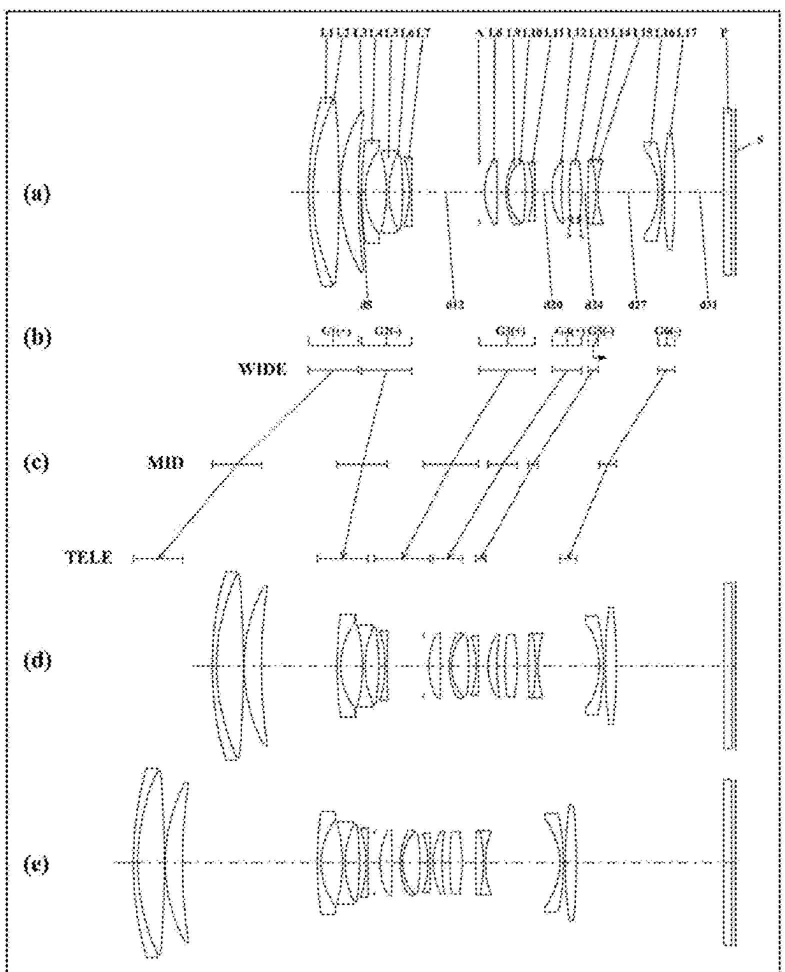


FIG. 1A

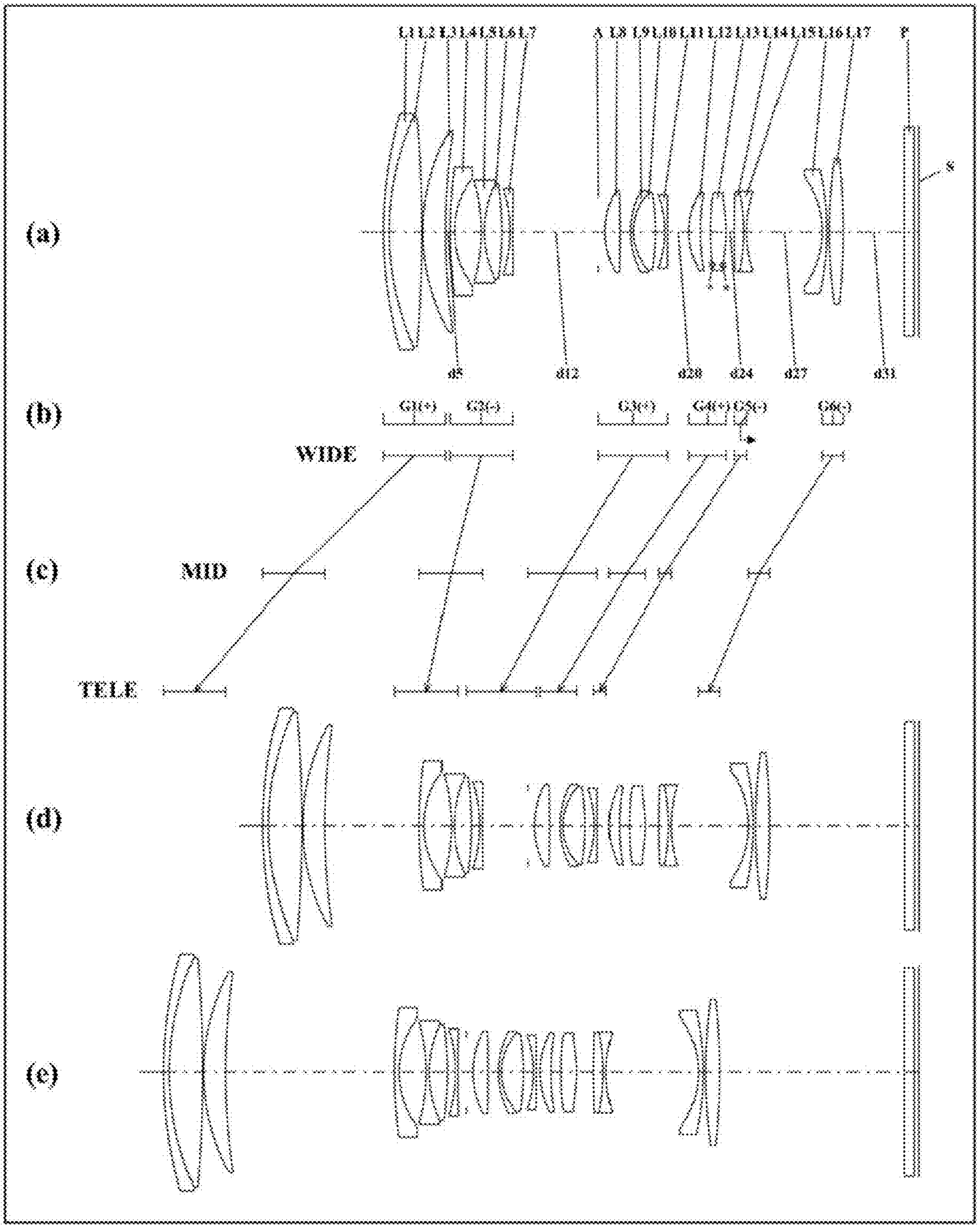
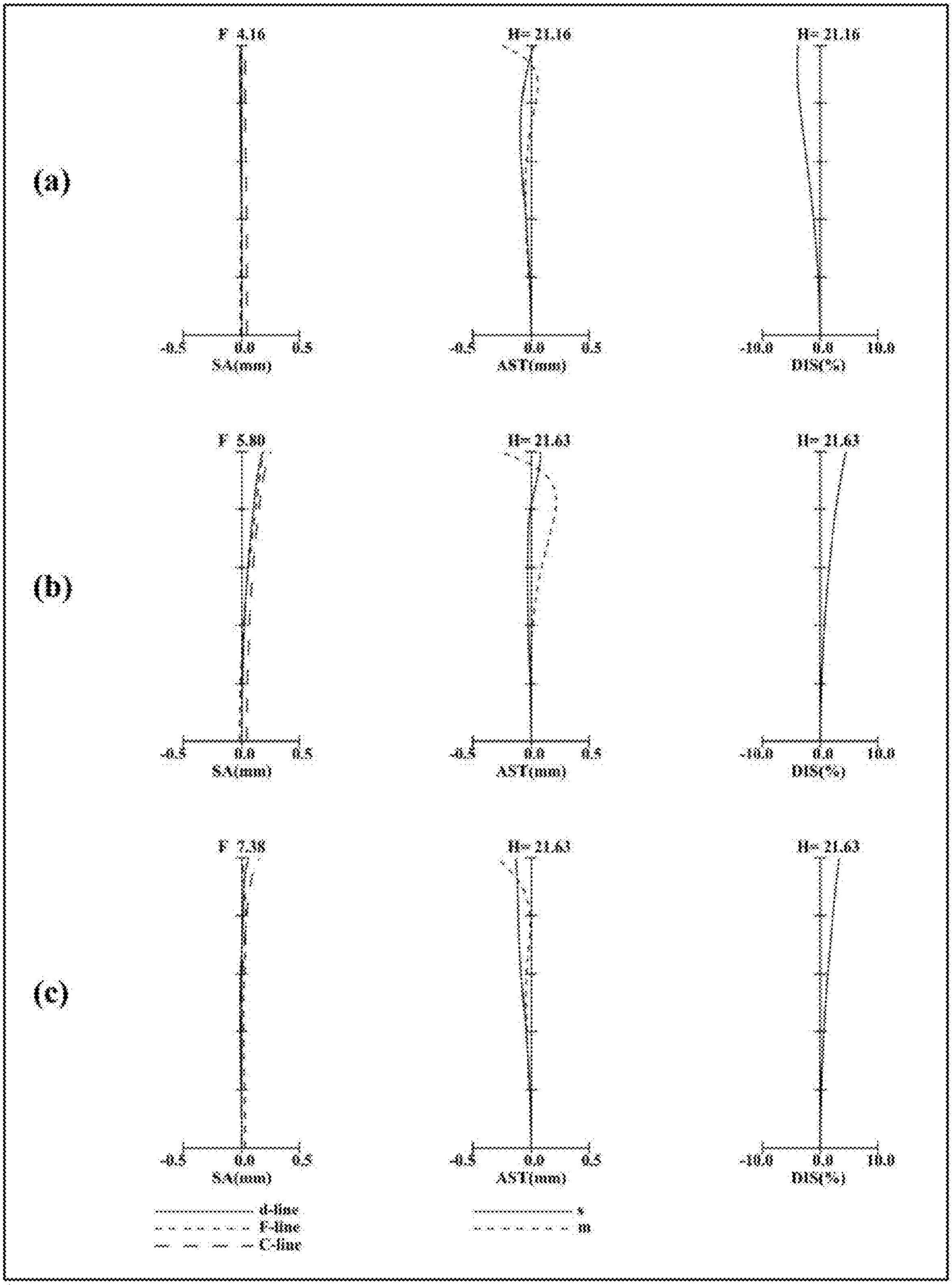

L1 L2 L3 L4 L5 L6 L7
A L8 L9 L10 L11 L12 L13 L14 L15 L16 L17
P
S
(a)
d5
d12
d20
d24
d27
d31
(b)
G1(+)
G2(-)
G3(+)
G4(+)
G5(-)
G6(-)
WIDE
(c)
MID
TELE
(d)
(e)

FIG. 1B



(a)
F 4.16
H= 21.16
H= 21.16
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
(b)
F 5.80
H= 21.63
H= 21.63
SA(mm)
AST(mm)
DIS(%)
(c)
F 7.38
H= 21.63
H= 21.63
SA(mm)
AST(mm)
DIS(%)
d-line
F-line
C-line
s
m

FIG. 1C

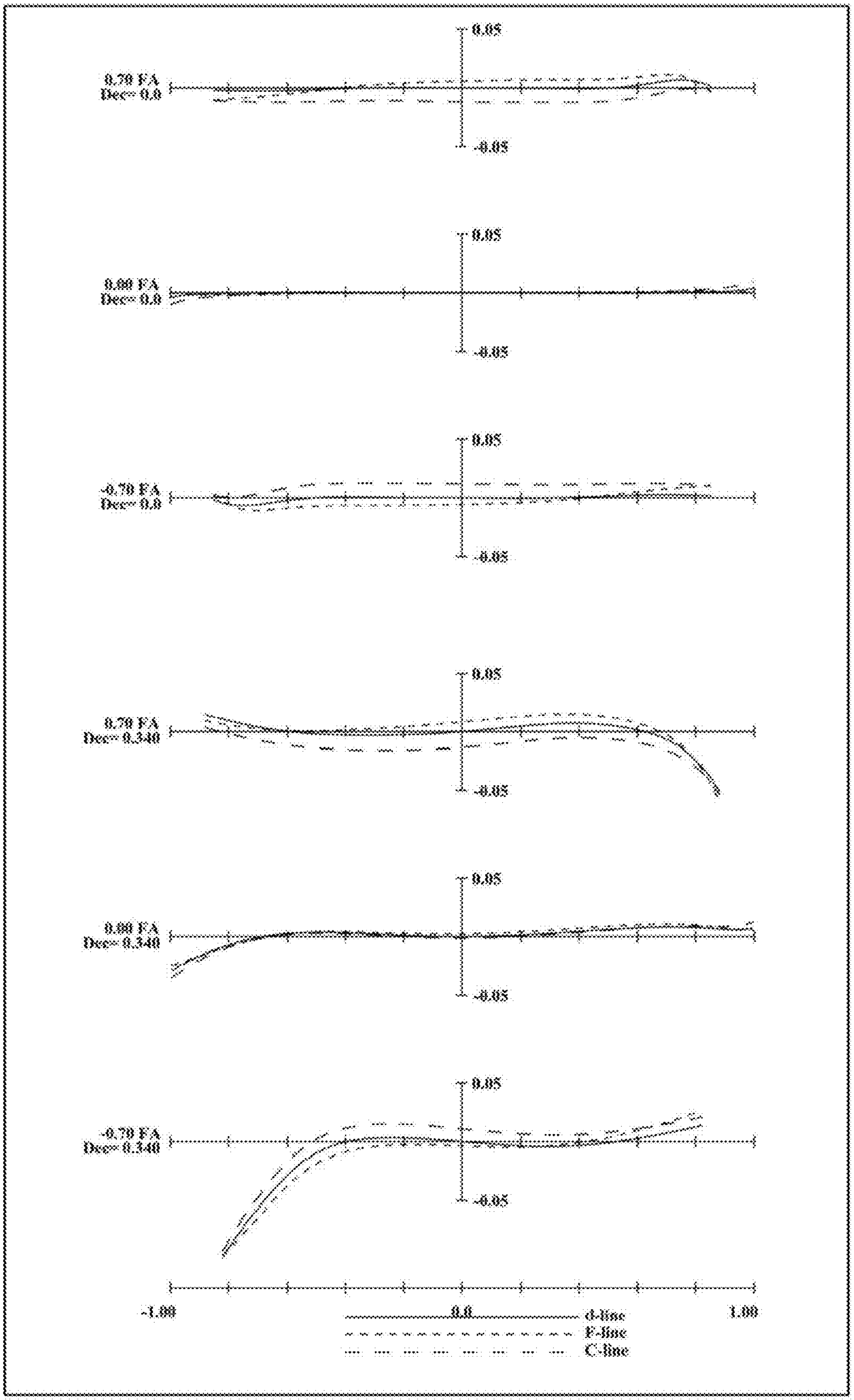

0.05
0.70 FA
Dec= 0.0
-0.05
0.05
0.00 FA
Dec= 0.0
-0.05
0.05
-0.70 FA
Dec= 0.0
-0.05
0.05
0.70 FA
Dec= 0.340
-0.05
0.05
0.00 FA
Dec= 0.340
-0.05
0.05
-0.70 FA
Dec= 0.340
-0.05
-1.00
0.0
1.00
d-line
F-line
C-line

FIG. 2A

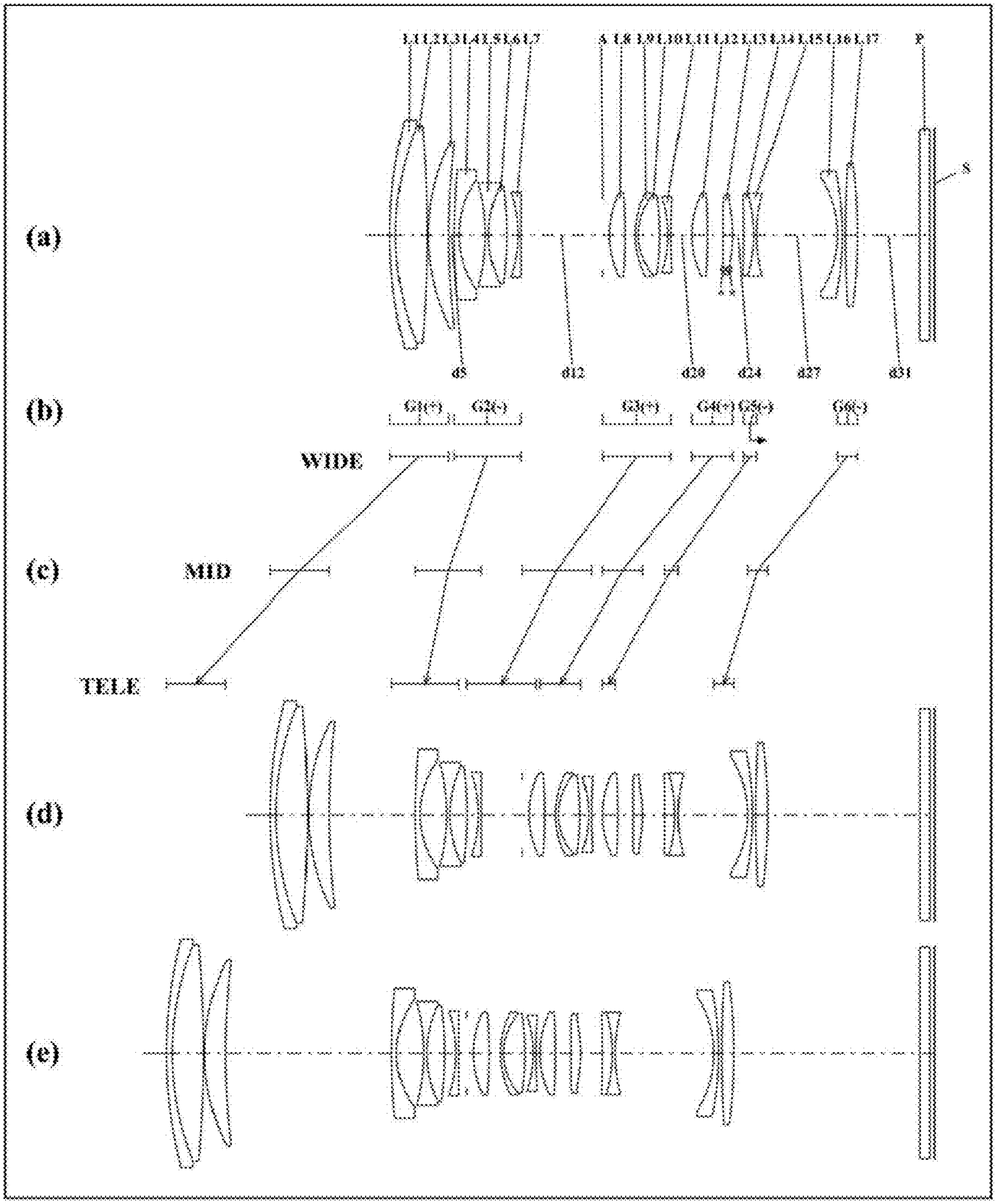
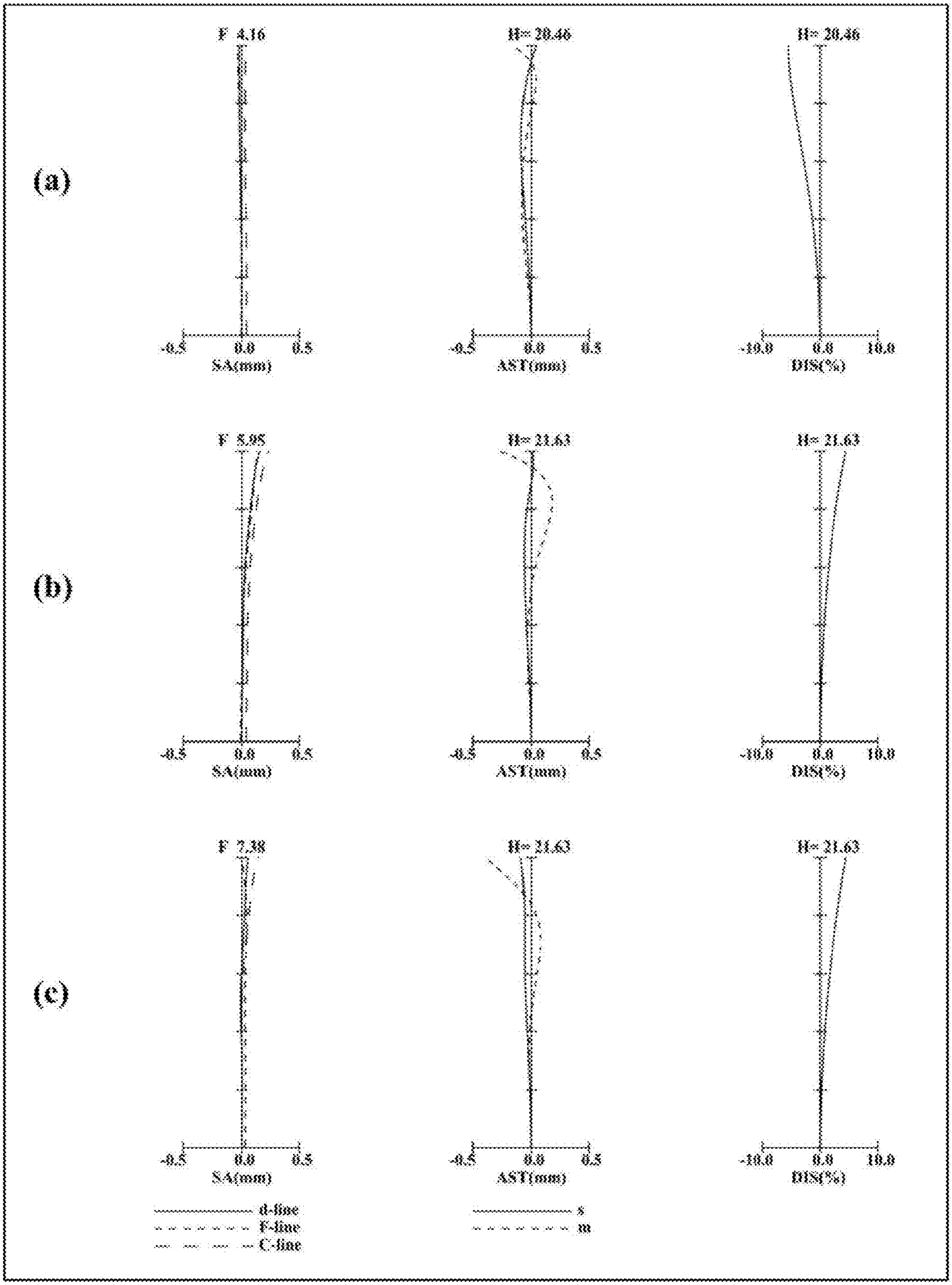
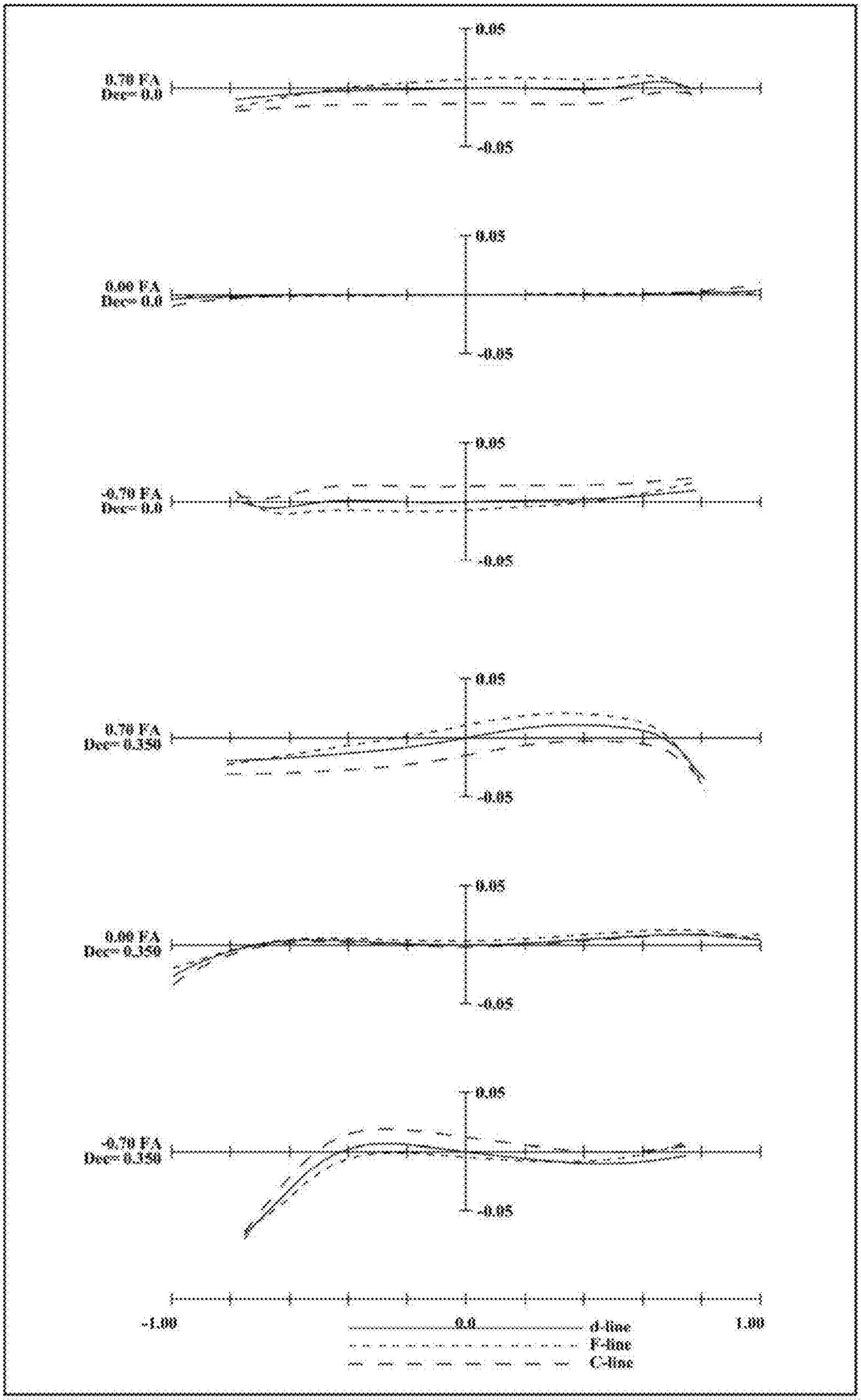

L1 L2 L3 L4 L5 L6 L7
A L8 L9 L10 L11 L12 L13 L14 L15 L16 L17
P
S
(a)
d5
d12
d20
d24
d27
d31
(b)
G1(+)
G2(-)
G3(+)
G4(+)
G5(-)
G6(-)
WIDE
(c)
MID
TELE
(d)
(e)

FIG. 2B



F 4.16
H= 28.46
H= 28.46
(a)
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
F 5.95
H= 21.63
H= 21.63
(b)
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
F 7.38
H= 21.63
H= 21.63
(c)
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
d-line
F-line
C-line
s
m

FIG. 2C



0.05
0.70 FA
Dec= 0.0
-0.05
0.05
0.00 FA
Dec= 0.0
-0.05
0.05
-0.70 FA
Dec= 0.0
-0.05
0.05
0.70 FA
Dec= 0.350
-0.05
0.05
0.00 FA
Dec= 0.350
-0.05
0.05
-0.70 FA
Dec= 0.350
-0.05
-1.00
0.0
1.00
d-line
F-line
C-line

FIG. 3A

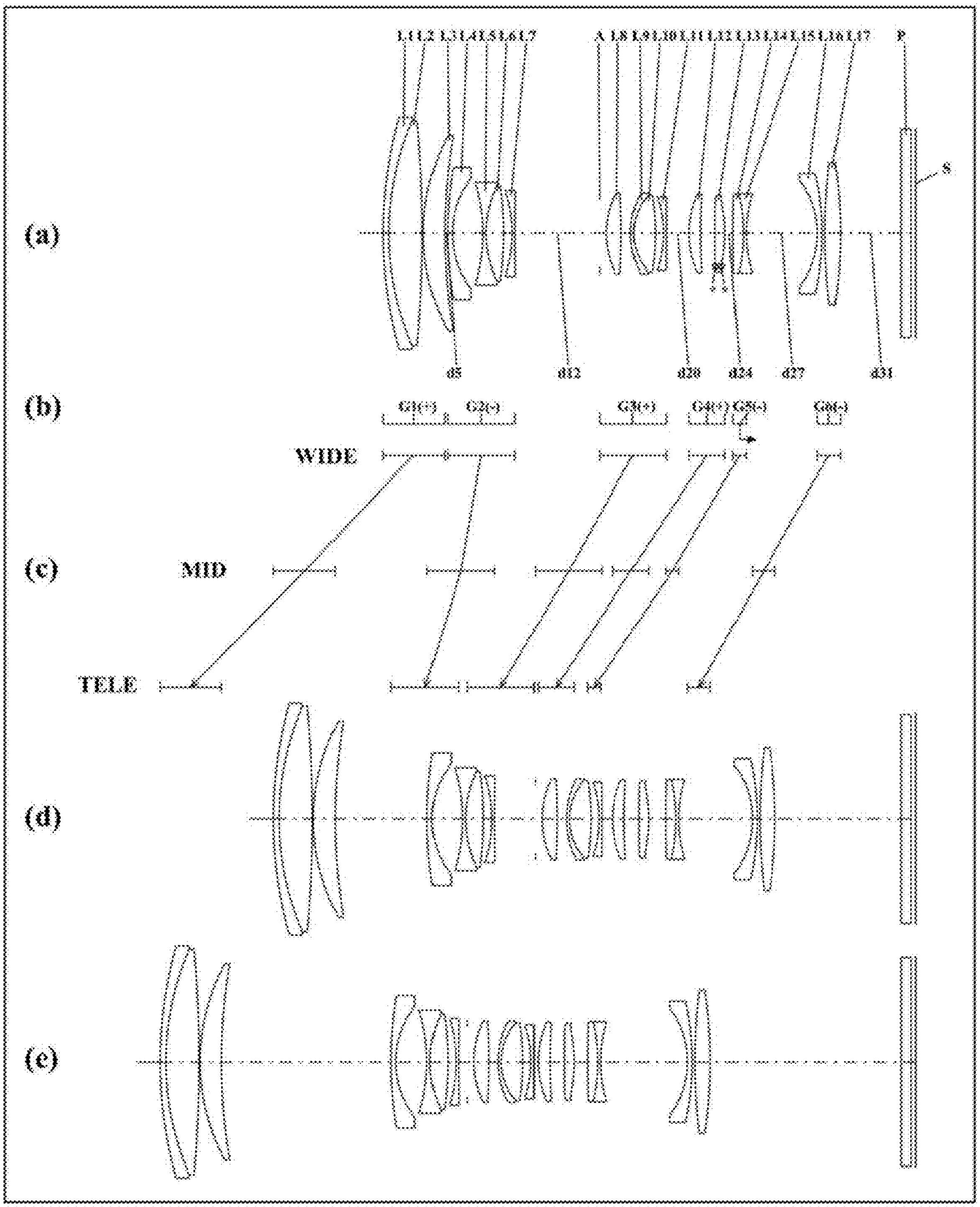

L1 L2 L3 L4 L5 L6 L7
A L8 L9 L10 L11 L12 L13 L14 L15 L16 L17
P
S
(a)
d5
d12
d20
d24
d27
d31
(b)
G1(+) G2(-)
G3(+) G4(+) G5(-)
G6(-)
WIDE
(c)
MID
TELE
(d)
(e)

FIG. 3B

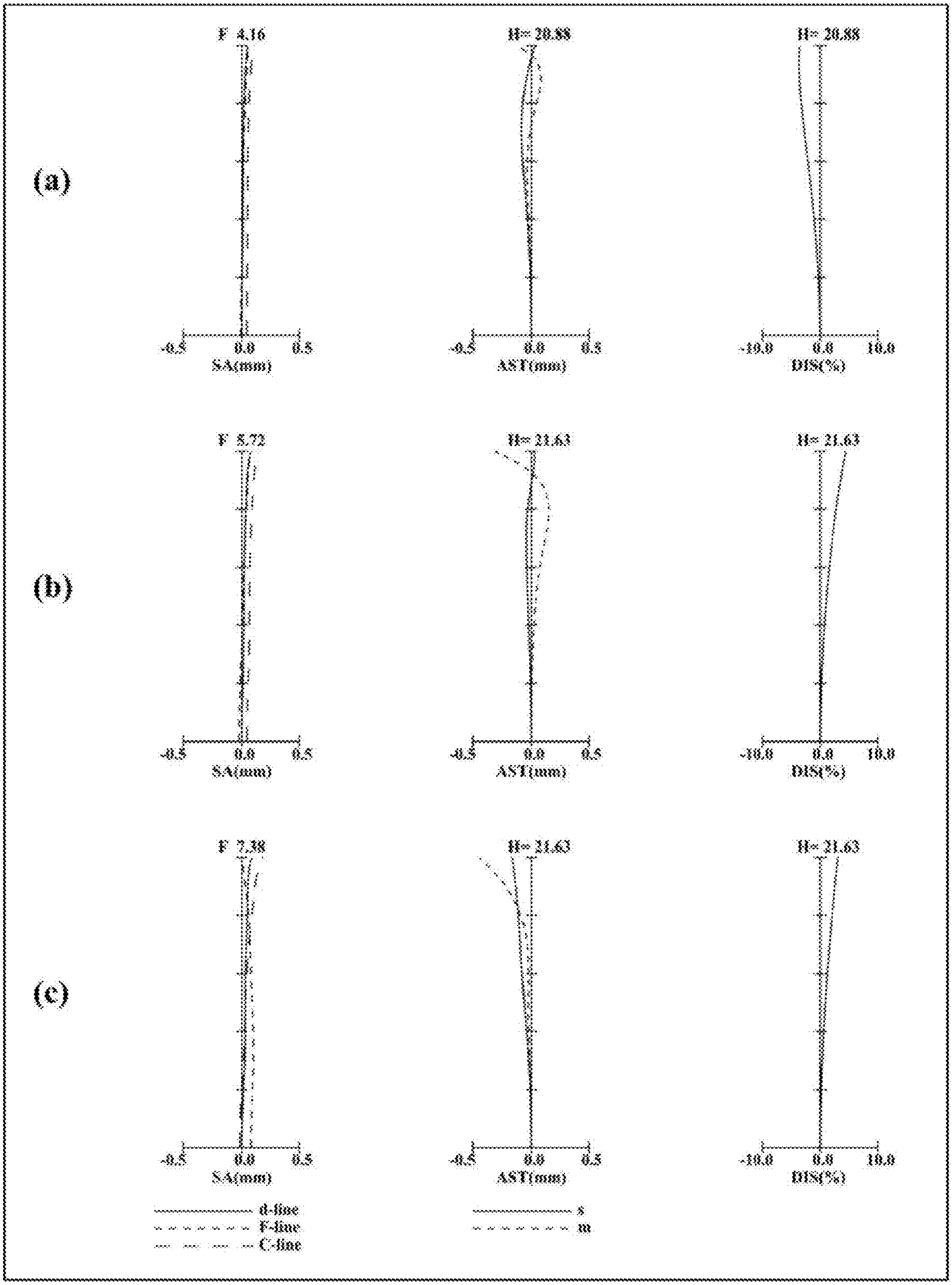
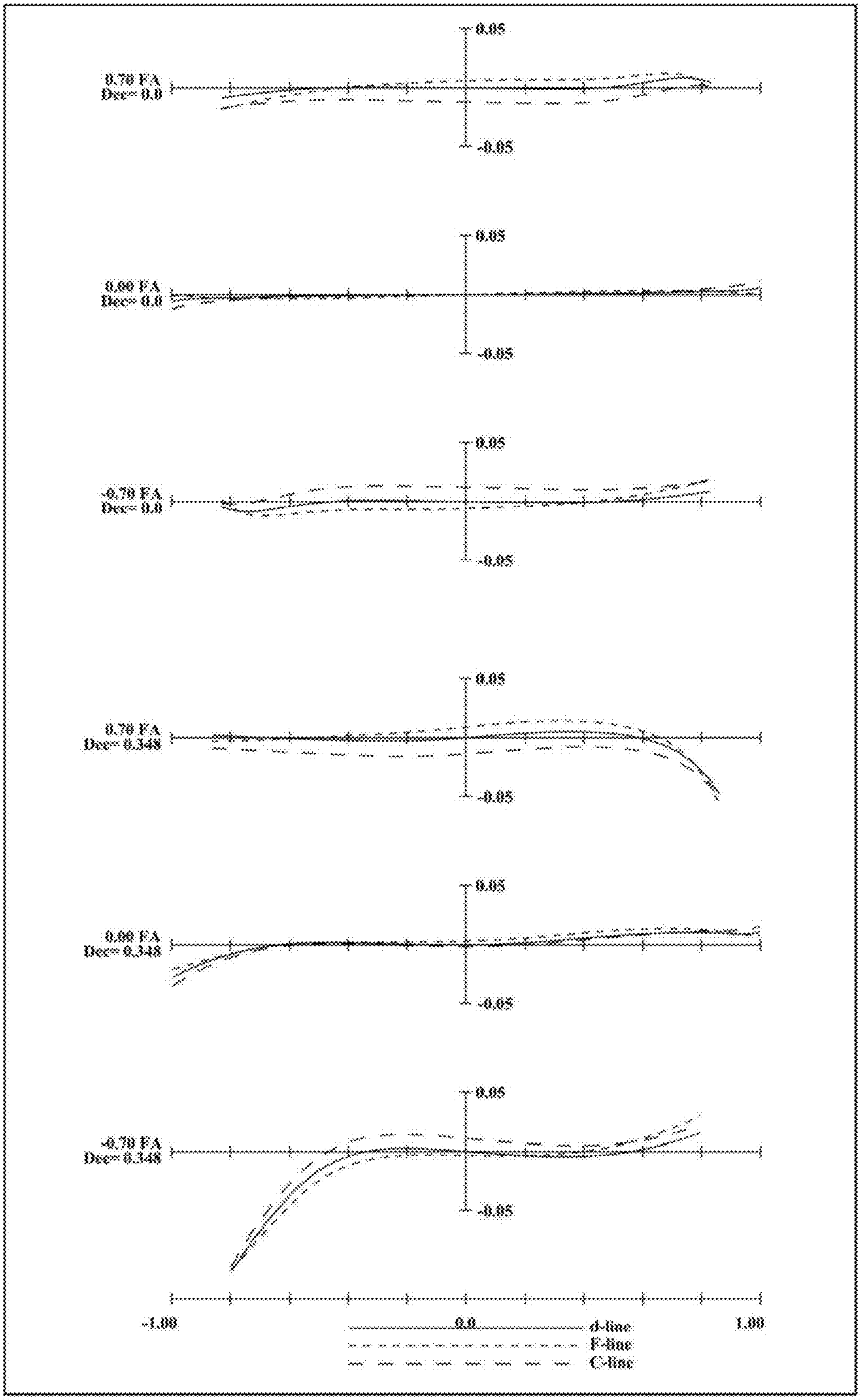

(a)
F 4.16
H= 28.88
H= 28.88
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
(b)
F 5.72
H= 21.63
H= 21.63
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
(c)
F 7.38
H= 21.63
H= 21.63
-0.5 0.0 0.5
SA(mm)
-0.5 0.0 0.5
AST(mm)
-10.0 0.0 10.0
DIS(%)
d-line
F-line
C-line
s
m

FIG. 3C


0.05
0.70 FA
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-0.05
0.05
0.00 FA
Dec= 0.0
-0.05
0.05
-0.70 FA
Dec= 0.0
-0.05
0.05
0.70 FA
Dec= 0.348
-0.05
0.05
0.00 FA
Dec= 0.348
-0.05
0.05
-0.70 FA
Dec= 0.348
-0.05
-1.00
0.0
1.00
d-line
F-line
C-line

FIG. 4A

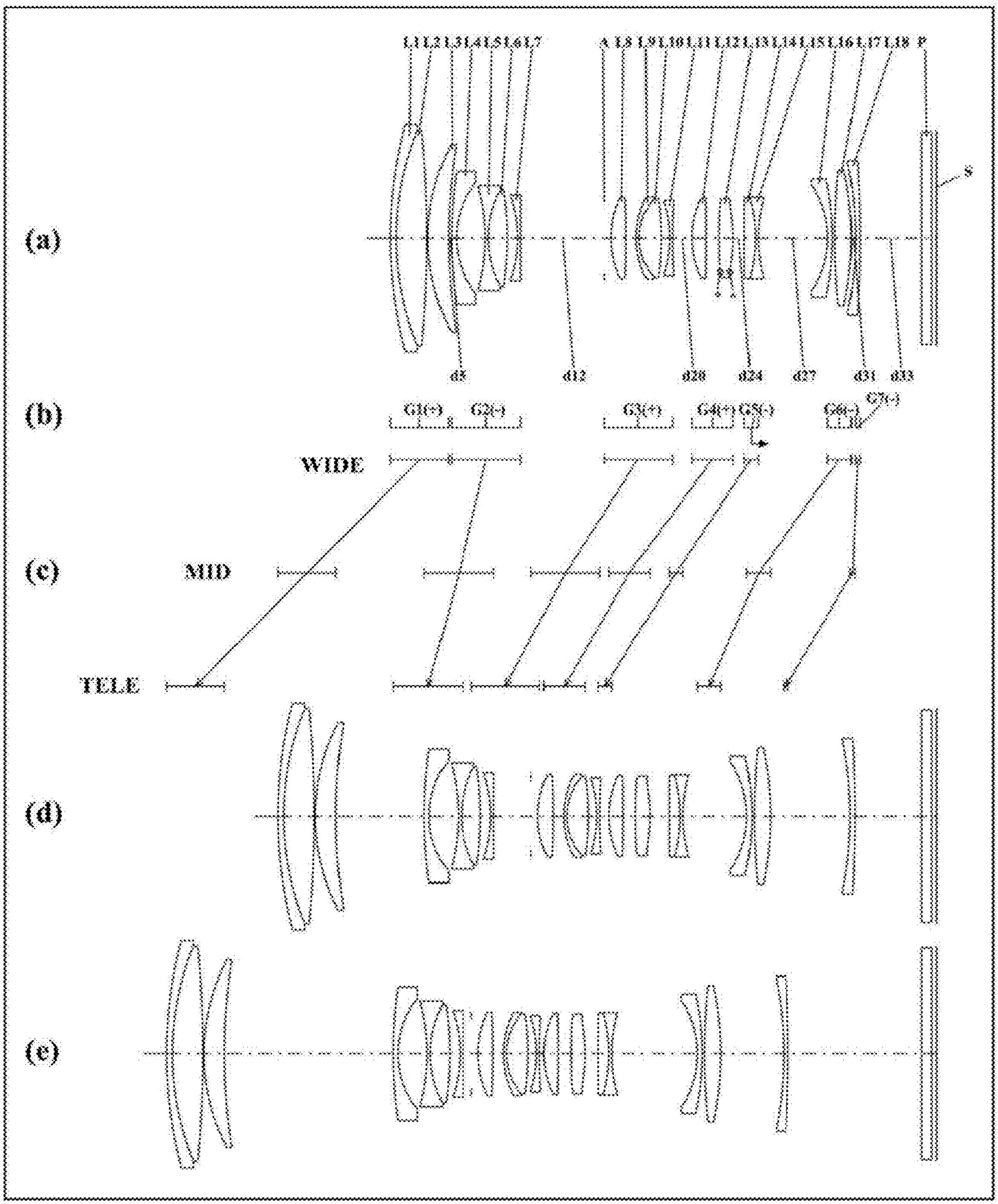
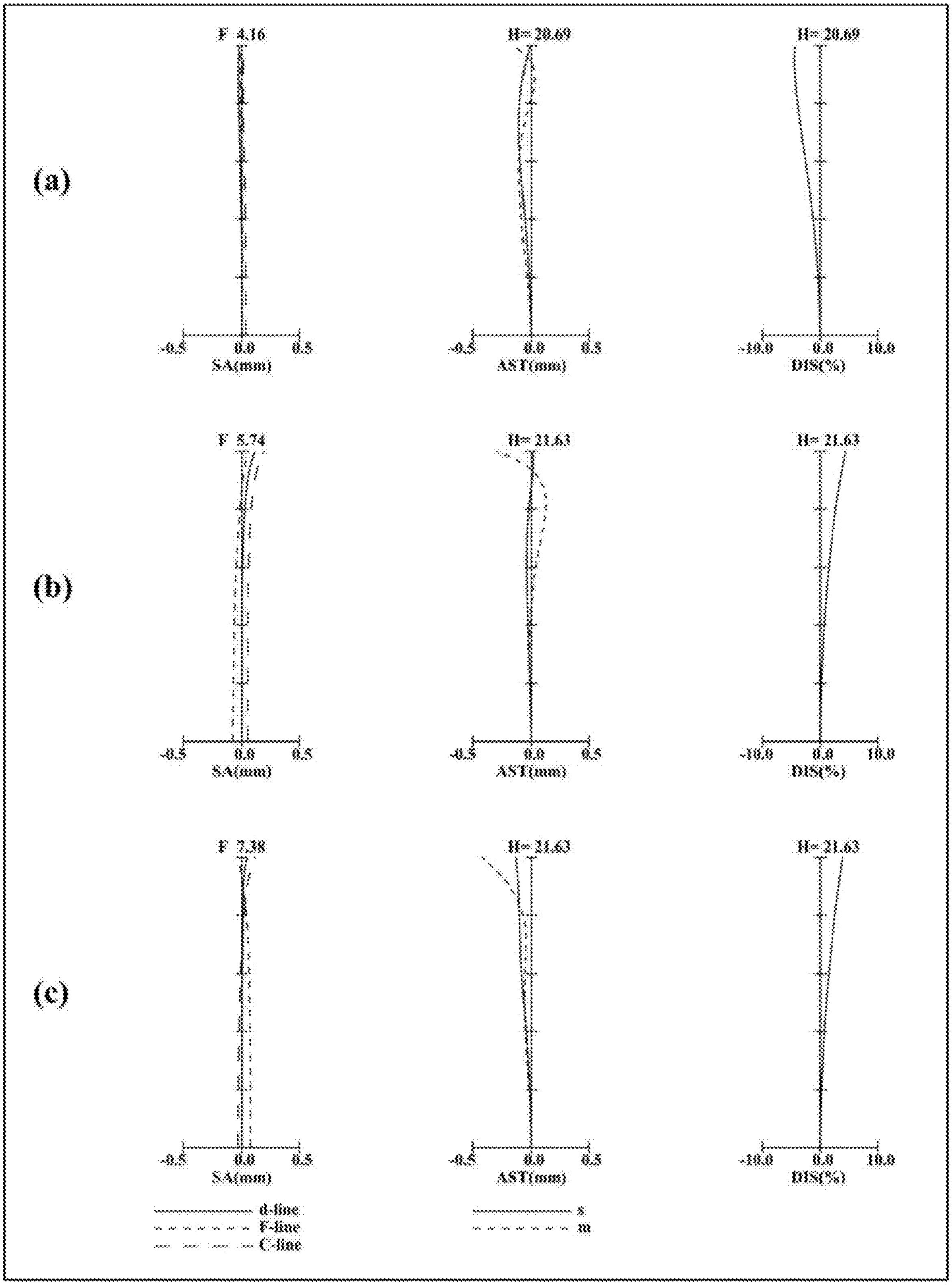

L1 L2 L3 L4 L5 L6 L7
A L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 P
S
(a)
d5
d12
d20
d24
d27
d31
d33
(b)
G1(+)
G2(-)
G3(+)
G4(+)
G5(-)
G6(-)
G7(-)
(c)
WIDE
MID
TELE
(d)
(e)

FIG. 4B



F 4.16
H= 28.69
H= 28.69
(a)
-0.5
0.0
0.5
SA(mm)
-0.5
0.0
0.5
AST(mm)
-10.0
0.0
10.0
DIS(%)
F 5.74
H= 21.63
H= 21.63
(b)
-0.5
0.0
0.5
SA(mm)
-0.5
0.0
0.5
AST(mm)
-10.0
0.0
10.0
DIS(%)
F 7.38
H= 21.63
H= 21.63
(c)
-0.5
0.0
0.5
SA(mm)
-0.5
0.0
0.5
AST(mm)
-10.0
0.0
10.0
DIS(%)
d-line
F-line
C-line
s
m

FIG. 4C

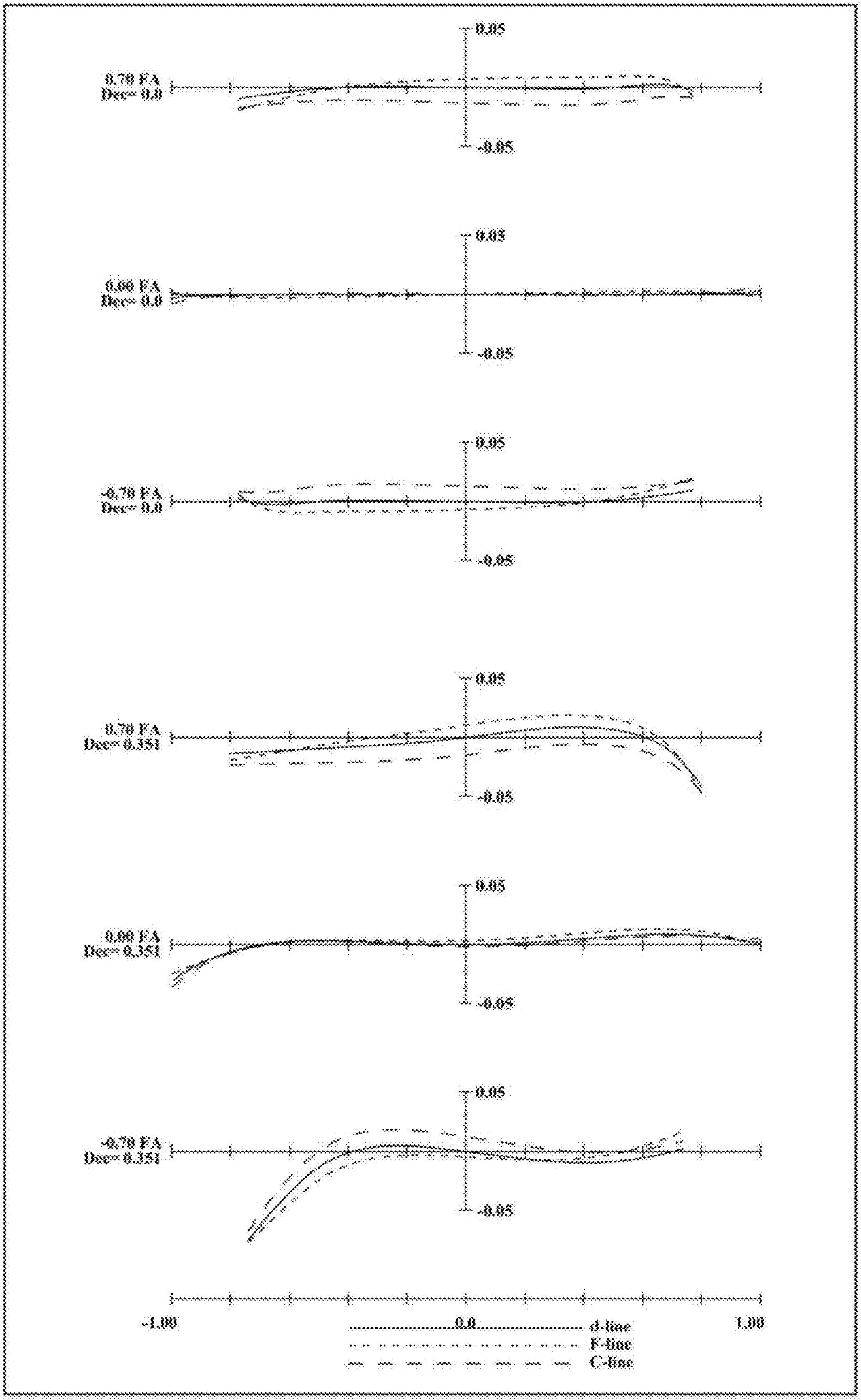

0.05
0.70 FA
Dec= 0.0
-0.05
0.05
0.00 FA
Dec= 0.0
-0.05
0.05
-0.70 FA
Dec= 0.0
-0.05
0.05
0.70 FA
Dec= 0.351
-0.05
0.05
0.00 FA
Dec= 0.351
-0.05
0.05
-0.70 FA
Dec= 0.351
-0.05
-1.00
0.0
1.00
d-line
F-line
C-line

FIG. 5A

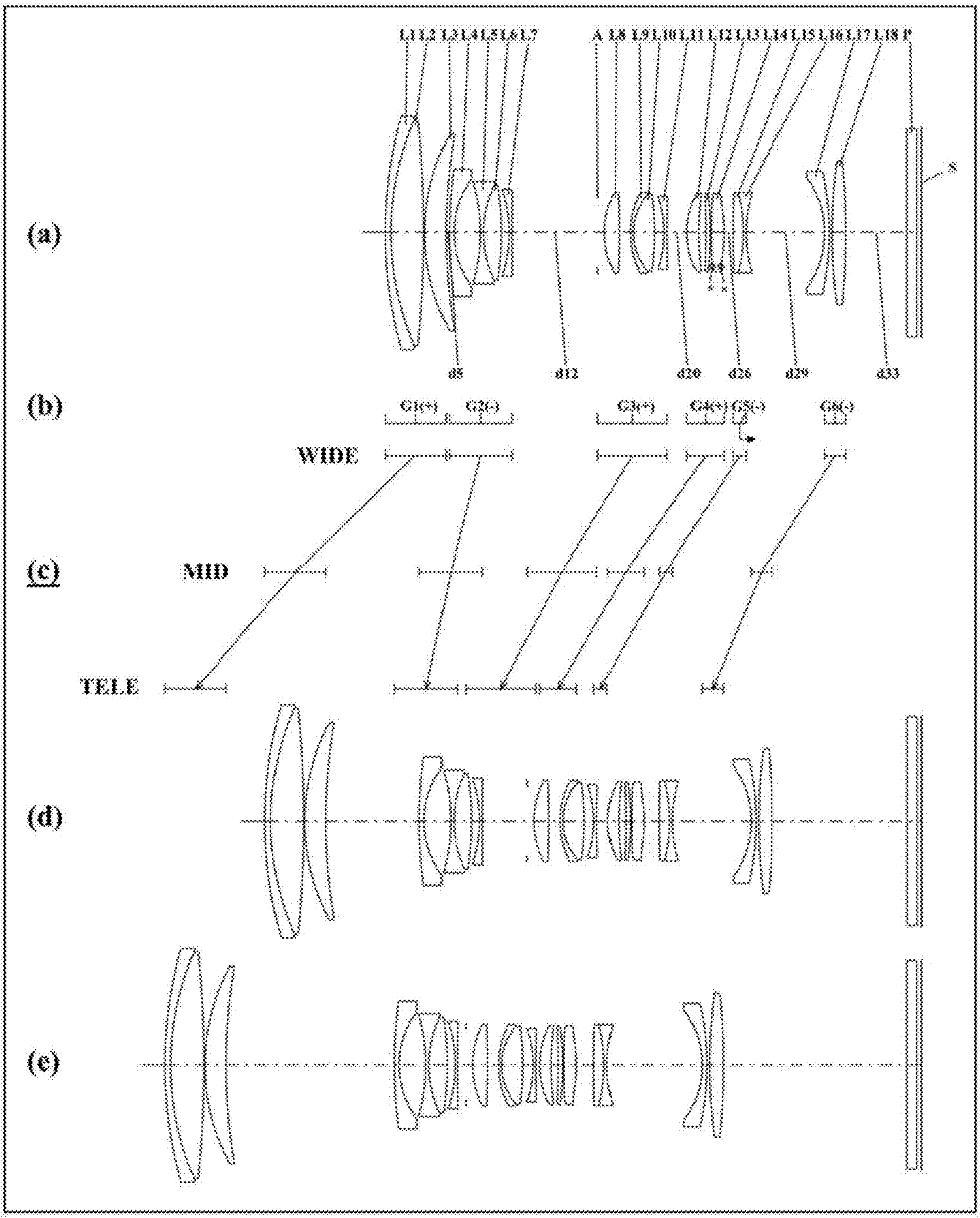

L1 L2 L3 L4 L5 L6 L7
A L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 P
S
(a)
d8
d12
d20
d26
d29
d33
(b)
G1(+) G2(-)
G3(+) G4(+) G5(-)
G6(-)
WIDE
(c)
MID
TELE
(d)
(e)

FIG. 5B

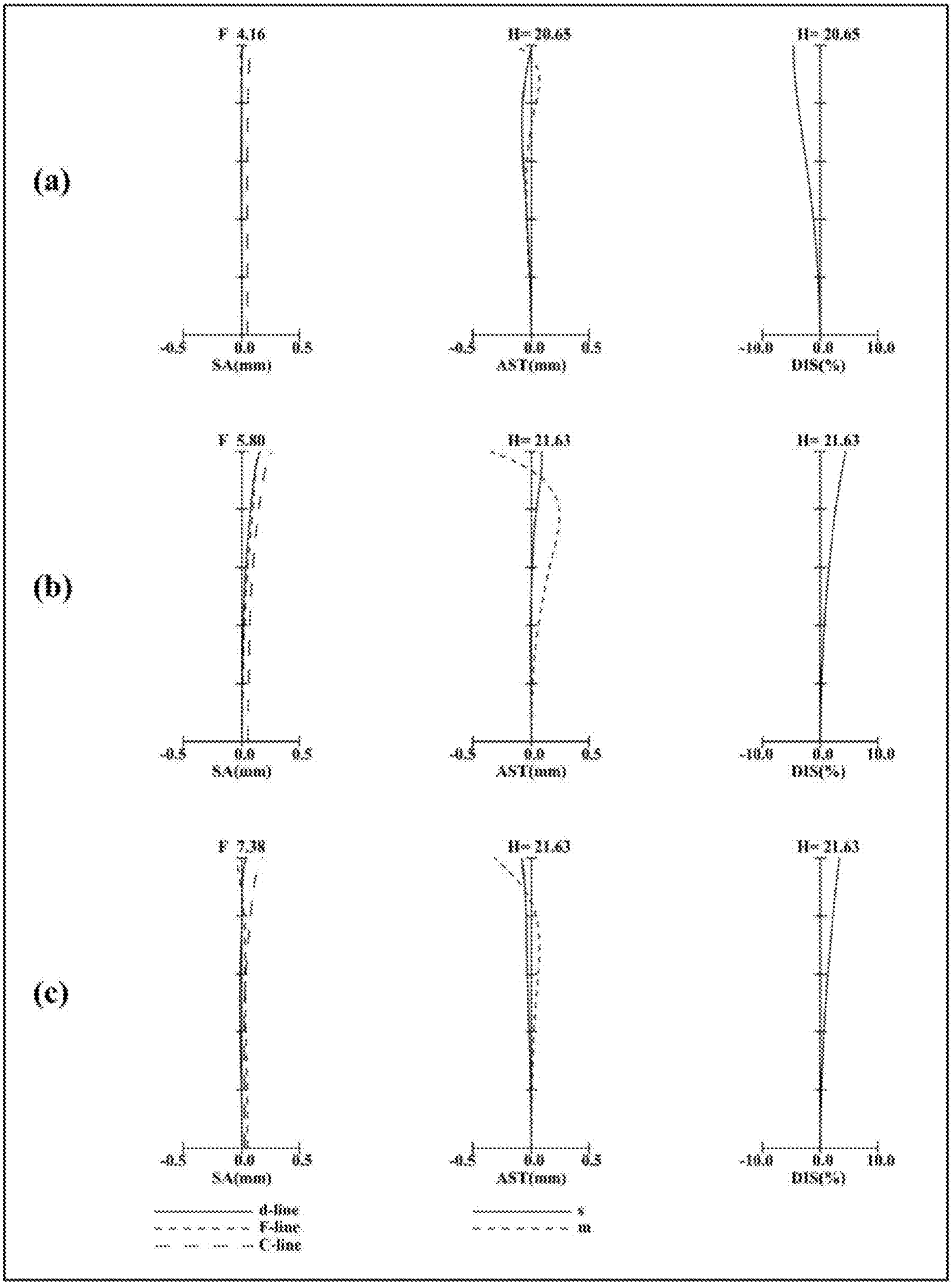

(a)
F 4.16
H= 28.65
H= 28.65
-0.5 0.0 0.5
SA(mm)
AST(mm)
-10.0 0.0 10.0
DIS(%)
(b)
F 5.88
H= 21.63
H= 21.63
(c)
F 7.38
H= 21.63
H= 21.63
d-line
F-line
C-line
s
m

FIG. 5C

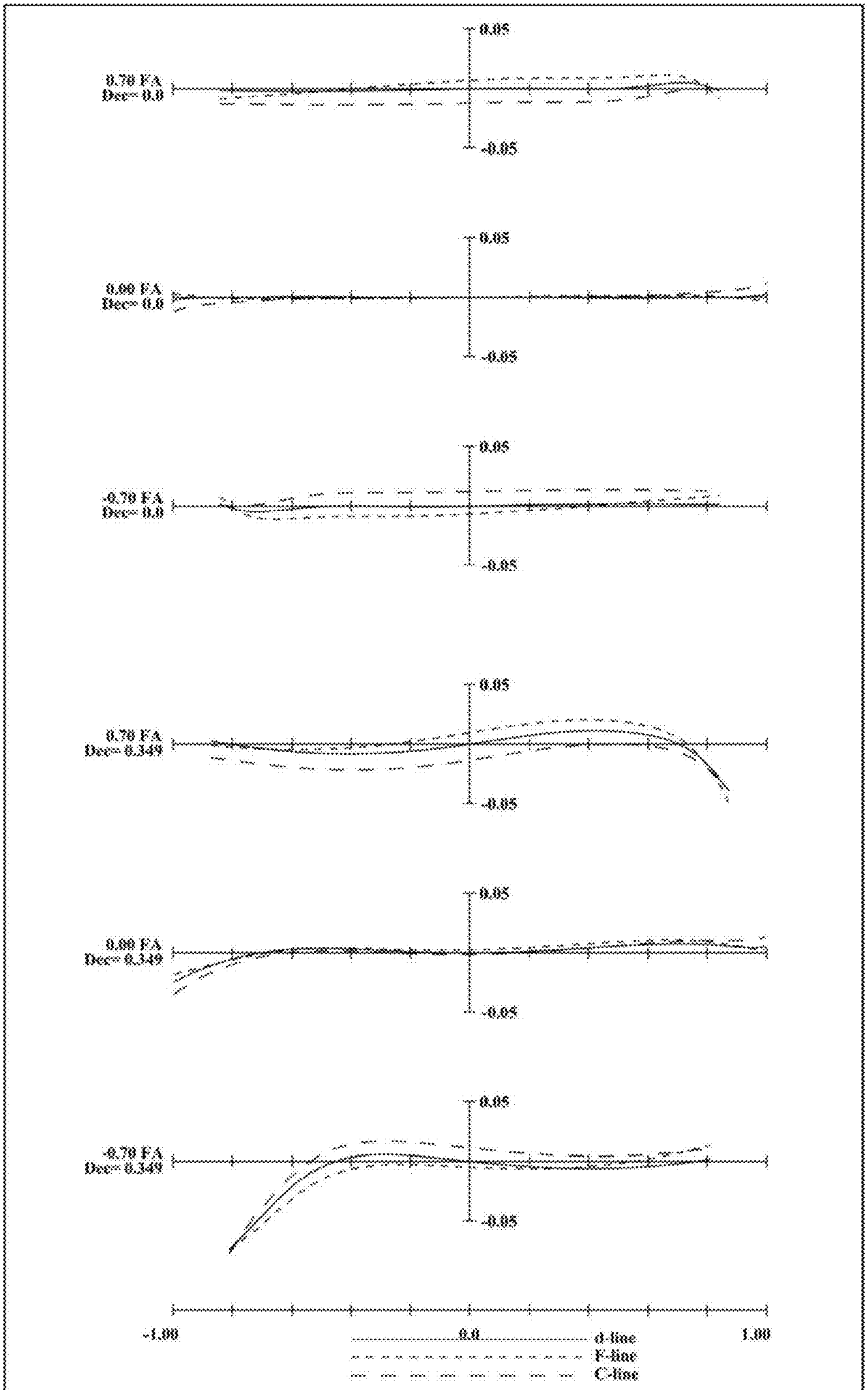

0.05
0.70 FA
Dec= 0.0
-0.05
0.05
0.00 FA
Dec= 0.0
-0.05
0.05
-0.70 FA
Dec= 0.0
-0.05
0.05
0.70 FA
Dec= 0.349
-0.05
0.05
0.00 FA
Dec= 0.349
-0.05
0.05
-0.70 FA
Dec= 0.349
-0.05
-1.00
0.0
1.00
d-line
F-line
C-line

FIG. 6

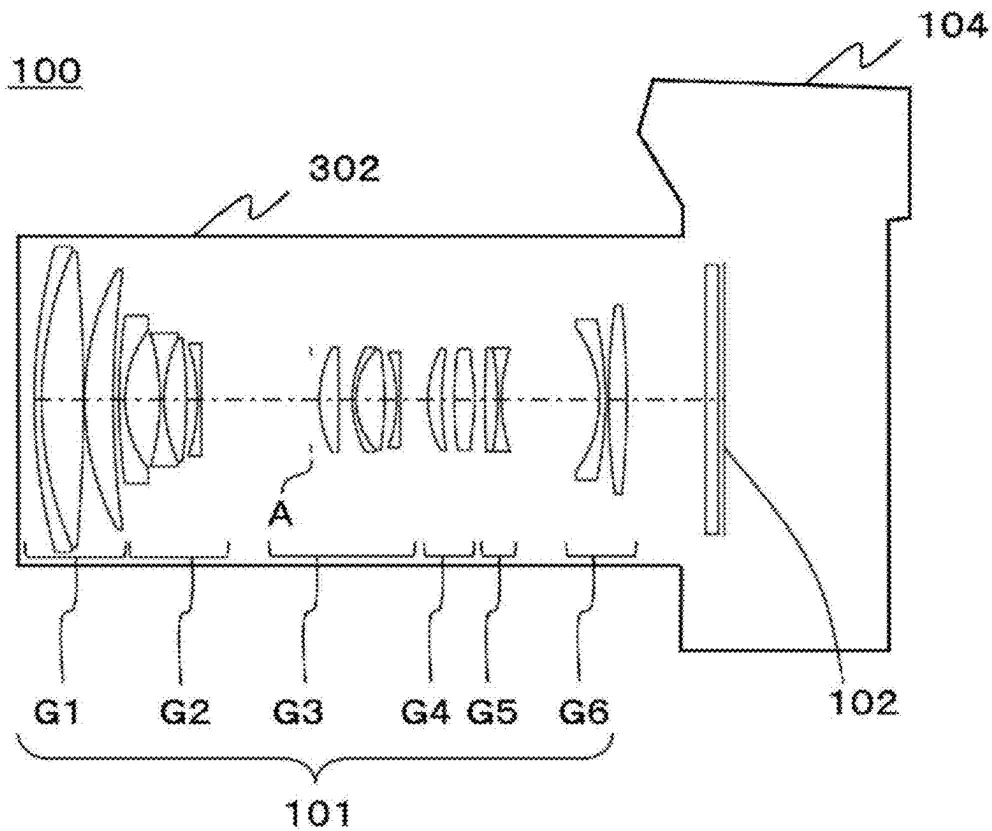
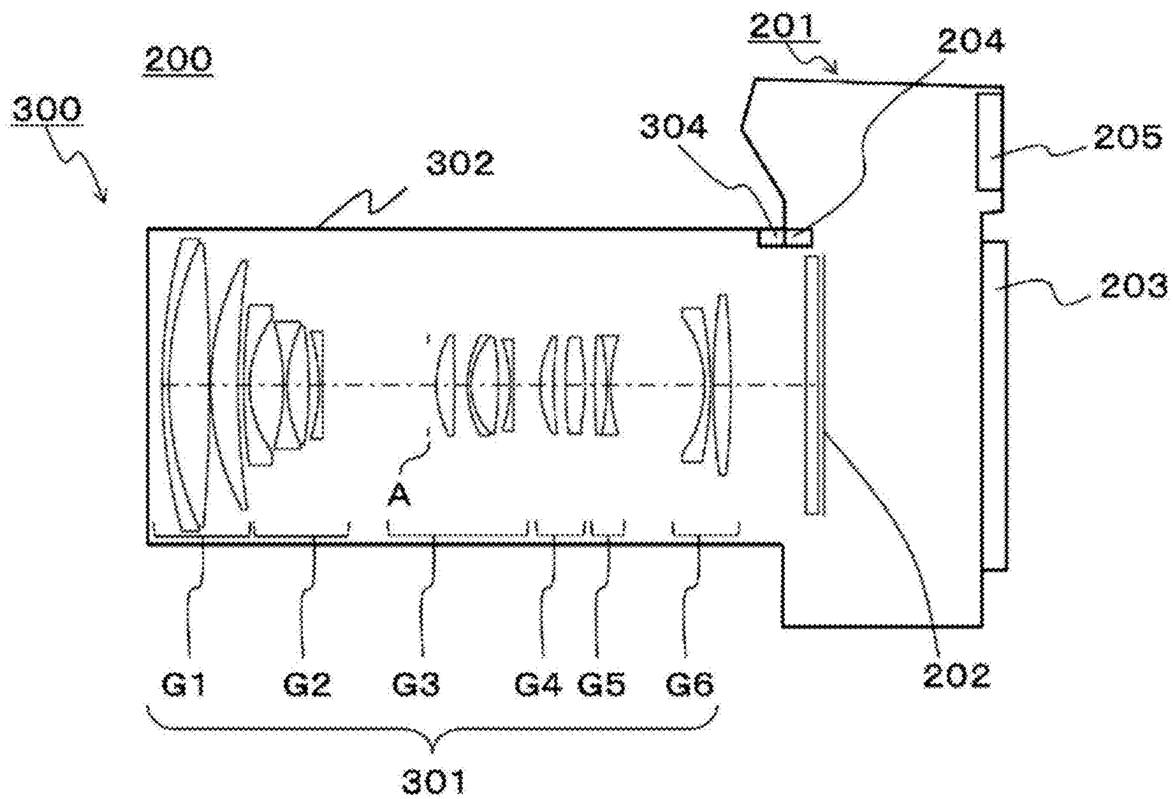


FIG. 7



IMAGING OPTICAL SYSTEM, AND IMAGE CAPTURE DEVICE AND CAMERA SYSTEM INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is based upon, and claims the benefit of priority to, Japanese Patent Application No. 2024-023382, filed on Feb. 20, 2024, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to an imaging optical system having the ability to compensate for various types of aberrations sufficiently over the entire zoom range, and also relates to an image capture device and interchangeable lens unit including such an imaging optical system.

BACKGROUND ART

[0003] JP 2023-104137 A discloses a zoom lens including a first lens group L**1** having positive refractive power, a second lens group L**2** having negative refractive power, a third lens group L**3** having positive refractive power, a fourth lens group L**4** having positive refractive power, and an N^{th} lens group LN having negative refractive power. The first, second, third, fourth, and N^{th} lens groups L**1**, L**2**, L**3**, L**4**, and LN are arranged in this order such that the first lens group L**1** is located closer to an object than any of the other second, third, fourth, and N^{th} lens groups is, and that the N^{th} lens group is located closer to an image plane than any of the other first, second, third, and fourth lens groups is. In the zoom lens, the interval between adjacent lens groups changes while the zoom lens system is zooming.

SUMMARY

[0004] The present disclosure provides an imaging optical system having the ability to compensate for various types of aberrations sufficiently over the entire zoom range and an image capture device and interchangeable lens unit including such an imaging optical system. An imaging optical system according to the present disclosure includes: a first lens group having positive power; a second lens group having negative power; a third lens group having positive power; a fourth lens group having positive power; a fifth lens group having negative power; and a sixth lens group having power. The first, second, third, fourth, fifth, and sixth lens groups are arranged in this order such that the first lens group is located closer to an object than any of the second, third, fourth, fifth or sixth lens group is, and that the sixth lens group is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group is. An interval between each pair of lens groups that are adjacent to each other changes as at least the first, second, third, fourth, fifth, and sixth lens groups move in an optical axis direction aligned with an optical axis of the imaging optical system while the imaging optical system is zooming.

BRIEF DESCRIPTION OF DRAWINGS

[0005] The figures depict one or more implementations in accordance with the present teaching, by way of example only, not by way of limitations. In the figures, like reference numerals refer to the same or similar elements.

[0006] FIG. **1**A illustrates lens arrangements showing an infinity in-focus state of an imaging optical system according to a first embodiment (corresponding to a first example of numerical values);

[0007] FIG. **1**B illustrates longitudinal aberration diagrams showing the infinity in-focus state of the imaging optical system in the first example of numerical values;

[0008] FIG. **1**C illustrates lateral aberration diagrams showing a basic state where the imaging optical system is making no image blur compensation and an image blur compensated state where the imaging optical system is making image blur compensation, respectively, at a telephoto end in the first example of numerical values;

[0009] FIG. **2**A illustrates lens arrangements showing an infinity in-focus state of an imaging optical system according to a second embodiment (corresponding to a second example of numerical values);

[0010] FIG. **2**B illustrates longitudinal aberration diagrams showing the infinity in-focus state of the imaging optical system in the second example of numerical values;

[0011] FIG. **2**C illustrates lateral aberration diagrams showing a basic state where the imaging optical system is making no image blur compensation and an image blur compensated state where the imaging optical system is making image blur compensation, respectively, at a telephoto end in the second example of numerical values;

[0012] FIG. **3**A illustrates lens arrangements showing an infinity in-focus state of an imaging optical system according to a third embodiment (corresponding to a third example of numerical values);

[0013] FIG. **3**B illustrates longitudinal aberration diagrams showing the infinity in-focus state of the imaging optical system in the third example of numerical values;

[0014] FIG. **3**C illustrates lateral aberration diagrams showing a basic state where the imaging optical system is making no image blur compensation and an image blur compensated state where the imaging optical system is making image blur compensation, respectively, at a telephoto end in the third example of numerical values;

[0015] FIG. **4**A illustrates lens arrangements showing an infinity in-focus state of an imaging optical system according to a fourth embodiment (corresponding to a fourth example of numerical values);

[0016] FIG. **4**B illustrates longitudinal aberration diagrams showing the infinity in-focus state of the imaging optical system in the fourth example of numerical values;

[0017] FIG. **4**C illustrates lateral aberration diagrams showing a basic state where the imaging optical system is making no image blur compensation and an image blur compensated state where the imaging optical system is making image blur compensation, respectively, at a telephoto end in the fourth example of numerical values;

[0018] FIG. **5**A illustrates lens arrangements showing an infinity in-focus state of an imaging optical system according to a fifth embodiment (corresponding to a fifth example of numerical values);

[0019] FIG. **5**B illustrates longitudinal aberration diagrams showing the infinity in-focus state of the imaging optical system in the fifth example of numerical values;

[0020] FIG. **5**C illustrates lateral aberration diagrams showing a basic state where the imaging optical system is making no image blur compensation and an image blur compensated state where the imaging optical system is making image blur compensation, respectively, at a telephoto end in the fifth example of numerical values;

[0021] FIG. **6** illustrates a schematic configuration for an image capture device according to the first embodiment; and

[0022] FIG. **7** illustrates a schematic configuration for a camera system according to the first embodiment.

DETAILED DESCRIPTION

[0023] Embodiments of the present disclosure will now be described in detail with reference to the accompanying drawings as needed. Note that unnecessarily detailed description will be omitted. For example, detailed description of already well-known matters and redundant description of substantially the same configuration will be omitted. This is done to avoid making the following description overly redundant and thereby help one of ordinary skill in the art understand the present disclosure easily.

[0024] In addition, note that the accompanying drawings and the following description are provided to help one of ordinary skill in the art understand the present disclosure fully and should not be construed as limiting the scope of the present disclosure, which is defined by the appended claims.

First to Fifth Embodiments

[0025] Imaging optical systems according to first to fifth embodiments will now be described on an individual basis with reference to the accompanying drawings.

[0026] FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A illustrate lens arrangements of imaging optical systems according to first to fifth embodiments, respectively. In each of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the imaging optical system is in an infinity in-focus state.

[0027] In FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, portion (a) illustrates a lens arrangement at a wide-angle end (which is a state with the shortest focal length fw); portion (d) illustrates a lens arrangement at a middle position (which is a state with a middle focal length $fM=\sqrt{(fw*fT)}$); and portion (e) illustrates a lens arrangement at a telephoto end (which is a state with the longest focal length fT). Note that portions (a), (d), and (e) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A have the same aspect ratio.

[0028] Furthermore, in portion (a) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the asterisk (*) attached to a surface of a particular lens indicates that the surface is an aspheric surface. Note that in the lenses shown in portion (a) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, an object-side surface or an image-side surface having no asterisks is a spherical surface.

[0029] Also, in FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the polygon arrows shown in portion (c) thereof each connect together the respective positions of the lens groups at the wide-angle end (WIDE), middle position (MID), and telephoto end (TELE) from top to bottom. Note that these polygon arrows just connect the wide-angle end to the middle position and the middle position to the telephoto end with the lines, and do not indicate the actual movement of the lens groups.

[0030] Furthermore, in portion (b) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the respective lens groups are designated by the reference signs G**1**-G**6** (or G**1**-G**7**) corresponding to their respective positions shown in portion (a).

[0031] Furthermore, the signs (+) and (−) added to the reference signs G**1**-G**7** of the respective lens groups in portion (b) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A indicate the powers of the respective lens groups G**1**-G**7**. That is to say, the positive sign (+) indicates positive power, and the negative sign (−) indicates negative power.

[0032] Also, the arrows added to the lens groups in portion (b) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A each indicate focusing to make a transition from the infinity in-focus state toward the close-object in-focus state. Note that in FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the reference signs of respective lens groups are shown under the respective lens groups in portion (a) thereof, and therefore, an arrow indicating focusing is shown under the sign of each lens group for convenience's sake. In each zooming state, the directions of movement of the respective lens groups during focusing will be described more specifically later with respect to each of the first through fifth embodiments.

[0033] Furthermore, in portions (a), (d), and (e) of FIGS. **1**A, **2**A, **3**A, **4**A, and **5**A, the straight line drawn at the right end indicates the position of the image plane S (i.e., a surface, facing the object, of the image sensor). Therefore, the left end of the drawings corresponds to the object side. Furthermore, a parallel plate P such as a low-pass filter or cover glass is disposed between the lens group on the last stage, facing the image plane S, of the imaging optical system and the image plane S.

[0034] Note that the "optical axis" as used herein refers to the "optical axis of the imaging optical system" unless otherwise stated.

First Embodiment

[0035] FIG. **1**A illustrates an imaging optical system according to a first embodiment.

[0036] The imaging optical system includes: a first lens group G**1** having positive power; a second lens group G**2** having negative power; a third lens group G**3** having positive power; a fourth lens group G**4** having positive power; a fifth lens group G**5** having negative power; and a sixth lens group G**6** having negative power. The first, second, third, fourth, fifth, and sixth lens groups G**1**, G**2**, G**3**, G**4**, G**5**, G**6** are arranged in this order such that the first lens group G**1** is located closer to an object than any of the second, third, fourth, fifth, or sixth lens group G**2**, G**3**, G**4**, G**5**, G**6** is and that the sixth lens group G**6** is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group G**1**, G**2**, G**3**, G**4**, G**5** is.

[0037] The imaging optical system forms an image at a point on the image plane S.

[0038] The first lens group G**1** is made up of: a first lens L**1** having negative power; a second lens L**2** having positive power; and a third lens L**3** having positive power. The first lens L**1**, the second lens L**2**, and the third lens L**3** are arranged in this order such that the first lens L**1** is located closer to the object than any other member of this first lens group G**1** is and that the third lens L**3** is located closer to the image plane than any other member of this first lens group G**1** is. The first lens L**1** and the second lens L**2** are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the first lens L**1** and the second lens L**2**.

[0039] The second lens group G**2** is made up of: a fourth lens L**4** having negative power; a fifth lens L**5** having negative power; a sixth lens L**6** having positive power; and a seventh lens L**7** having negative power. The fourth, fifth, sixth, and seventh lenses L**4**, L**5**, L**6**, L**7** are arranged in this order such that the fourth lens L**4** is located closer to the object than any other member of this second lens group G2 is and that the seventh lens L7 is located closer to the image plane than any other member of this second lens group G2 is. The fifth lens L5 and the sixth lens L6 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifth lens L5 and the sixth lens L6.

[0040] The third lens group G3 is made up of: an aperture stop A; an eighth lens L8 having positive power; a ninth lens L9 having negative power; a tenth lens L10 having positive power; and an eleventh lens L11 having negative power. The aperture stop A and the eighth, ninth, tenth, and eleventh lenses L8, L9, L10, L11 are arranged in this order such that the aperture stop A is located closer to the object than any other member of this third lens group G3 is and that the eleventh lens L11 is located closer to the image plane than any other member of this third lens group G3 is. The ninth lens L9 and the tenth lens L10 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the ninth lens L9 and the tenth lens L10.

[0041] The fourth lens group G4 is made up of a twelfth lens L12 having positive power and a thirteenth lens L13 having positive power. The twelfth lens L12 is located closer to the object than the thirteenth lens L13 is. The thirteenth lens L13 is located closer to the image plane than the twelfth lens L12 is.

[0042] The fifth lens group G5 is made up of: a fourteenth lens L14 having positive power; and a fifteenth lens L5 having negative power. The fourteenth lens L14 is located closer to the object than the fifteenth lens L15 is. The fifteenth lens L15 is located closer to the image plane than the fourteenth lens L14 is. The fourteenth lens L14 and the fifteenth lens L15 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fourteenth lens L14 and the fifteenth lens L15.

[0043] The sixth lens group G6 is made up of a sixteenth lens L16 having negative power and a seventeenth lens L17 having positive power. The sixteenth lens L16 is located closer to the object than the seventeenth lens L17 is. The seventeenth lens L17 is located closer to the image plane than the sixteenth lens L16 is.

[0044] The respective lenses will be described.

[0045] First, the respective lenses that form the first lens group G1 will be described. The first lens L1 is a meniscus lens having a convex surface facing the object. The second lens L2 is a biconvex lens. The third lens L3 is a meniscus lens having a convex surface facing the object.

[0046] Next, the respective lenses that form the second lens group G2 will be described. The fourth lens L4 is a meniscus lens having a convex surface facing the object. The fifth lens L5 is a biconcave lens. The sixth lens L6 is a biconvex lens. The seventh lens L7 is a biconcave lens.

[0047] Next, the respective lenses that form the third lens group G3 will be described. The eighth lens L8 is a biconvex lens. The ninth lens L9 is a meniscus lens having a convex surface facing the object. The tenth lens L10 is a biconvex lens. The eleventh lens L11 is a meniscus lens having a convex surface facing the image plane. In this case, the eighth lens L8 is an example of the lens LG3F1. The eighth lens L8 is an example of the group of fixed lenses G3Obj configured not to move perpendicularly to the optical axis during image stabilization. The ninth lens L9 is an example of the lens LG3F2. The ninth lens L9 and the tenth lens L10 are an example of a group of image stabilizer lenses that move perpendicularly to the optical axis during the image stabilization. The eleventh lens L11 is an example of the lens LG3R1. The eleventh lens L11 is an example of a group of fixed lenses G3Img that does not move perpendicularly to the optical axis during the image stabilization.

[0048] Next, the respective lenses that form the fourth lens group G4 will be described. The twelfth lens L12 is a meniscus lens having a convex surface facing the object. The thirteenth lens L13 is a biconvex lens. The object-side and image-side surfaces of the thirteenth lens L13 are aspheric surfaces. In this case, the twelfth lens L12 is an example of the lens LG4F1. The twelfth lens L12 is an example of the lens LG4Fp1. The thirteenth lens L13 is an example of the lens LG4F2.

[0049] Next, the respective lenses that form the fifth lens group G5 will be described. The fourteenth lens L14 is a biconvex lens. The fifteenth lens L15 is a biconcave lens.

[0050] Next, the respective lenses that form the sixth lens group G6 will be described. The sixteenth lens L16 is a meniscus lens having a convex surface facing the image plane. The seventeenth lens L17 is a biconvex lens.

[0051] While the imaging optical system according to the first embodiment is zooming from the wide-angle end toward the telephoto end during a shooting session, the first lens group G1, the second lens group G2, the third lens group G3, the fourth lens group G4, the fifth lens group G5, and the sixth lens group G6 all move toward the object with respect to the image plane S. In the meantime, as the imaging optical system is zooming, the first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 move along the optical axis such that the interval between the first lens group G1 and the second lens group G2 increases, the interval between the second lens group G2 and the third lens group G3 decreases, the interval between the third lens group G3 and the fourth lens group G4 decreases, the interval between the fourth lens group G4 and the fifth lens group G5 increases, and the interval between the fifth lens group G5 and the sixth lens group G6 increases.

[0052] While the imaging optical system according to the first embodiment is focusing to make a transition from the infinity in-focus state toward the close-object in-focus state, the fifth lens group G5 moves along the optical axis toward the image plane.

[0053] When any camera shake or any vibration caused by external force during a shooting session is detected by a gyrosensor provided for at least one of an interchangeable lens unit holding the imaging optical system or an image capture device to which the interchangeable lens unit is attached, the ninth lens L9 and the tenth lens L10 (forming the group of image stabilizer lenses) which belong to the third lens group G3 move perpendicularly to the optical axis (i.e., in a direction in which the image blur is reduced) to optically compensate for the image blur that may be caused by the camera shake or the vibration due to external force. These image blur compensation lenses (namely, the ninth lens L9 and the tenth lens L10) allow the imaging optical system to compensate for the shift of the image point due to the vibration of the overall system. That is to say, this allows the imaging optical system to optically compensate for the image blur due to camera shake, vibrations, and other disturbances.

Second Embodiment

[0054] FIG. **2**A illustrates an imaging optical system according to a second embodiment.

[0055] The imaging optical system includes: a first lens group G**1** having positive power; a second lens group G**2** having negative power; a third lens group G**3** having positive power; a fourth lens group G**4** having positive power; a fifth lens group G**5** having negative power; and a sixth lens group G**6** having negative power. The first, second, third, fourth, fifth, and sixth lens groups G**1**, G**2**, G**3**, G**4**, G**5**, G**6** are arranged in this order such that the first lens group G**1** is located closer to an object than any of the second, third, fourth, fifth, or sixth lens group G**2**, G**3**, G**4**, G**5**, G**6** is and that the sixth lens group G**6** is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group G**1**, G**2**, G**3**, G**4**, G**5** is.

[0056] The imaging optical system forms an image at a point on the image plane S.

[0057] The first lens group G**1** is made up of: a first lens L**1** having negative power; a second lens L**2** having positive power; and a third lens L**3** having positive power. The first lens L**1**, the second lens L**2**, and the third lens L**3** are arranged in this order such that the first lens L**1** is located closer to the object than any other member of this first lens group G**1** is and that the third lens L**3** is located closer to the image plane than any other member of this first lens group G**1** is. The first lens L**1** and the second lens L**2** are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the first lens L**1** and the second lens L**2**.

[0058] The second lens group G**2** is made up of: a fourth lens L**4** having negative power; a fifth lens L**5** having negative power; a sixth lens L**6** having positive power; and a seventh lens L**7** having negative power. The fourth, fifth, sixth, and seventh lenses L**4**, L**5**, L**6**, L**7** are arranged in this order such that the fourth lens L**4** is located closer to the object than any other member of this second lens group G**2** is and that the seventh lens L**7** is located closer to the image plane than any other member of this second lens group G**2** is. The fifth lens L**5** and the sixth lens L**6** are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifth lens L**5** and the sixth lens L**6**.

[0059] The third lens group G**3** is made up of: an aperture stop A; an eighth lens L**8** having positive power; a ninth lens L**9** having negative power; a tenth lens L**10** having positive power, and an eleventh lens L**11** having negative power. The aperture stop A and the eighth, ninth, tenth, and eleventh lenses L**8**, L**9**, L**10**, L**11** are arranged in this order such that the aperture stop A is located closer to the object than any other member of this third lens group G**3** is and that the eleventh lens L**11** is located closer to the image plane than any other member of this third lens group G**3** is. The ninth lens L**9** and the tenth lens L**10** are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the ninth lens L**9** and the tenth lens L**10**.

[0060] The fourth lens group G**4** is made up of a twelfth lens L**12** having positive power and a thirteenth lens L**13** having positive power. The twelfth lens L**12** is located closer to the object than the thirteenth lens L**13** is. The thirteenth lens L**13** is located closer to the image plane than the twelfth lens L**12** is.

[0061] The fifth lens group G**5** is made up of: a fourteenth lens L**14** having positive power; and a fifteenth lens L**5** having negative power. The fourteenth lens L**14** is located closer to the object than the fifteenth lens L**15** is. The fifteenth lens L**15** is located closer to the image plane than the fourteenth lens L**14** is. The fourteenth lens L**14** and the fifteenth lens L**15** are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fourteenth lens L**14** and the fifteenth lens L**15**.

[0062] The sixth lens group G**6** is made up of a sixteenth lens L**16** having negative power and a seventeenth lens L**17** having positive power. The sixteenth lens L**16** is located closer to the object than the seventeenth lens L**17** is. The seventeenth lens L**17** is located closer to the image plane than the sixteenth lens L**16** is.

[0063] The respective lenses will be described.

[0064] First, the respective lenses that form the first lens group G**1** will be described. The first lens L**1** is a meniscus lens having a convex surface facing the object. The second lens L**2** is a biconvex lens. The third lens L**3** is a meniscus lens having a convex surface facing the object.

[0065] Next, the respective lenses that form the second lens group G**2** will be described. The fourth lens L**4** is a meniscus lens having a convex surface facing the object. The fifth lens L**5** is a biconcave lens. The sixth lens L**6** is a biconvex lens. The seventh lens L**7** is a biconcave lens.

[0066] Next, the respective lenses that form the third lens group G**3** will be described. The eighth lens L**8** is a biconvex lens. The ninth lens L**9** is a meniscus lens having a convex surface facing the object. The tenth lens L**10** is a biconvex lens. The eleventh lens L**11** is a biconcave lens. In this case, the eighth lens L**8** is an example of the lens LG**3**F**1**. The eighth lens L**8** is an example of the group of fixed lenses G**3**Obj configured not to move perpendicularly to the optical axis during image stabilization. The ninth lens L**9** is an example of the lens LG**3**F**2**. The ninth lens L**9** and the tenth lens L**10** are an example of a group of image stabilizer lenses that move perpendicularly to the optical axis during the image stabilization. The eleventh lens L**11** is an example of the lens LG**3**R**1**. The eleventh lens L**11** is an example of a group of fixed lenses G**3**Img that does not move perpendicularly to the optical axis during the image stabilization.

[0067] Next, the respective lenses that form the fourth lens group G**4** will be described. The twelfth lens L**12** is a biconvex lens. The thirteenth lens L**13** is a biconvex lens. The object-side and image-side surfaces of the thirteenth lens L**13** are aspheric surfaces. In this case, the twelfth lens L**12** is an example of the lens LG**4**F**1**. The twelfth lens L**12** is an example of the lens LG**4**Fp**1**. The thirteenth lens L**13** is an example of the lens LG**4**F**2**.

[0068] Next, the respective lenses that form the fifth lens group G**5** will be described. The fourteenth lens L**14** is a meniscus lens having a convex surface facing the image plane. The fifteenth lens L**15** is a biconcave lens.

[0069] Next, the respective lenses that form the sixth lens group G**6** will be described. The sixteenth lens L**16** is a meniscus lens having a convex surface facing the image plane. The seventeenth lens L**17** is a biconvex lens.

[0070] While the imaging optical system according to the second embodiment is zooming from the wide-angle end toward the telephoto end during a shooting session, the first lens group G**1**, the second lens group G**2**, the third lens group G**3**, the fourth lens group G**4**, the fifth lens group G**5**, and the sixth lens group G6 all move toward the object with respect to the image plane S. In the meantime, as the imaging optical system is zooming, the first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 move along the optical axis such that the interval between the first lens group G1 and the second lens group G2 increases, the interval between the second lens group G2 and the third lens group G3 decreases, the interval between the third lens group G3 and the fourth lens group G4 decreases, the interval between the fourth lens group G4 and the fifth lens group G5 increases from the wide-angle end through a middle position but decreases from the middle position through the telephoto end, and the interval between the fifth lens group G5 and the sixth lens group G6 decreases from the wide-angle end through the middle position but increases from the middle position through the telephoto end.

[0071] While the imaging optical system according to the second embodiment is focusing to make a transition from the infinity in-focus state toward the close-object in-focus state, the fifth lens group G5 moves along the optical axis toward the image plane.

[0072] Meanwhile, the ninth lens L9 and the tenth lens L10 (forming the group of image stabilizer lenses) which belong to the third lens group G3 move perpendicularly to the optical axis to optically compensate for the image blur. These image blur compensation lenses (namely, the ninth lens L9 and the tenth lens L10) allow the imaging optical system to compensate for the shift of the image point due to the vibration of the overall system. That is to say, this allows the imaging optical system to optically compensate for the image blur due to camera shake, vibrations, and other disturbances.

Third Embodiment

[0073] FIG. 3A illustrates an imaging optical system according to a third embodiment.

[0074] The imaging optical system includes: a first lens group G1 having positive power; a second lens group G2 having negative power; a third lens group G3 having positive power; a fourth lens group G4 having positive power; a fifth lens group G5 having negative power; and a sixth lens group G6 having negative power. The first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 are arranged in this order such that the first lens group G1 is located closer to an object than any of the second, third, fourth, fifth, or sixth lens group G2, G3, G4, G5, G6 is and that the sixth lens group G6 is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group G1, G2, G3, G4, G5 is.

[0075] The imaging optical system forms an image at a point on the image plane S.

[0076] The first lens group G1 is made up of: a first lens L1 having negative power; a second lens L2 having positive power; and a third lens L3 having positive power. The first lens L1, the second lens L2, and the third lens L3 are arranged in this order such that the first lens L1 is located closer to the object than any other member of this first lens group G1 is and that the third lens L3 is located closer to the image plane than any other member of this first lens group G1 is. The first lens L1 and the second lens L2 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the first lens L1 and the second lens L2. The second lens group G2 is made up of: a fourth lens L4 having negative power; a fifth lens L5 having negative power; a sixth lens L6 having positive power; and a seventh lens L7 having negative power. The fourth, fifth, sixth, and seventh lenses L4, L5, L6, L7 are arranged in this order such that the fourth lens L4 is located closer to the object than any other member of this second lens group G2 is and that the seventh lens L7 is located closer to the image plane than any other member of this second lens group G2 is. The fifth lens L5 and the sixth lens L6 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifth lens L5 and the sixth lens L6.

[0077] The third lens group G3 is made up of: an aperture stop A; an eighth lens L8 having positive power; a ninth lens L9 having negative power; a tenth lens L10 having positive power; and an eleventh lens L11 having negative power. The aperture stop A and the eighth, ninth, tenth, and eleventh lenses L8, L9, L10, L11 are arranged in this order such that the aperture stop A is located closer to the object than any other member of this third lens group G3 is and that the eleventh lens L11 is located closer to the image plane than any other member of this third lens group G3 is. The ninth lens L9 and the tenth lens L10 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the ninth lens L9 and the tenth lens L10.

[0078] The fourth lens group G4 is made up of a twelfth lens L12 having positive power and a thirteenth lens L13 having positive power. The twelfth lens L12 is located closer to the object than the thirteenth lens L13 is. The thirteenth lens L13 is located closer to the image plane than the twelfth lens L12 is.

[0079] The fifth lens group G5 is made up of: a fourteenth lens L14 having positive power; and a fifteenth lens L5 having negative power. The fourteenth lens L14 is located closer to the object than the fifteenth lens L15 is. The fifteenth lens L15 is located closer to the image plane than the fourteenth lens L14 is. The fourteenth lens L14 and the fifteenth lens L15 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fourteenth lens L14 and the fifteenth lens L15.

[0080] The sixth lens group G6 is made up of a sixteenth lens L16 having negative power and a seventeenth lens L17 having positive power. The sixteenth lens L16 is located closer to the object than the seventeenth lens L17 is. The seventeenth lens L17 is located closer to the image plane than the sixteenth lens L16 is.

[0081] The respective lenses will be described.

[0082] First, the respective lenses that form the first lens group G1 will be described. The first lens L1 is a meniscus lens having a convex surface facing the object. The second lens L2 is a biconvex lens. The third lens L3 is a meniscus lens having a convex surface facing the object.

[0083] Next, the respective lenses that form the second lens group G2 will be described. The fourth lens L4 is a meniscus lens having a convex surface facing the object. The fifth lens L5 is a biconcave lens. The sixth lens L6 is a biconvex lens. The seventh lens L7 is a biconcave lens.

[0084] Next, the respective lenses that form the third lens group G3 will be described. The eighth lens L8 is a biconvex lens. The ninth lens L9 is a meniscus lens having a convex surface facing the object. The tenth lens L10 is a biconvex lens. The eleventh lens L11 is a meniscus lens having a convex surface facing the image plane. In this case, the eighth lens L8 is an example of the lens LG3F1. The eighth lens L8 is an example of the group of fixed lenses G3Obj configured not to move perpendicularly to the optical axis during image stabilization. The ninth lens L9 is an example of the lens LG3F2. The ninth lens L9 and the tenth lens L10 are an example of a group of image stabilizer lenses that move perpendicularly to the optical axis during the image stabilization. The eleventh lens L11 is an example of the lens LG3R1. The eleventh lens L11 is an example of a group of fixed lenses G3Img that does not move perpendicularly to the optical axis during the image stabilization.

[0085] Next, the respective lenses that form the fourth lens group G4 will be described. The twelfth lens L12 is a meniscus lens having a convex surface facing the object. The thirteenth lens L13 is a biconvex lens. The object-side and image-side surfaces of the thirteenth lens L13 are aspheric surfaces. In this case, the twelfth lens L12 is an example of the lens LG4F1. The twelfth lens L12 is an example of the lens LG4Fp1. The thirteenth lens L13 is an example of the lens LG4F2.

[0086] Next, the respective lenses that form the fifth lens group G5 will be described. The fourteenth lens L14 is a biconvex lens. The fifteenth lens L15 is a biconcave lens.

[0087] Next, the respective lenses that form the sixth lens group G6 will be described. The sixteenth lens L16 is a meniscus lens having a convex surface facing the image plane. The seventeenth lens L17 is a biconvex lens.

[0088] While the imaging optical system according to the third embodiment is zooming from the wide-angle end toward the telephoto end during a shooting session, the first lens group G1, the second lens group G2, the third lens group G3, the fourth lens group G4, the fifth lens group G5, and the sixth lens group G6 all move toward the object with respect to the image plane S. In the meantime, as the imaging optical system is zooming, the first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 move along the optical axis such that the interval between the first lens group G1 and the second lens group G2 increases, the interval between the second lens group G2 and the third lens group G3 decreases, the interval between the third lens group G3 and the fourth lens group G4 decreases, the interval between the fourth lens group G4 and the fifth lens group G5 increases from the wide-angle end through a middle position but decreases from the middle position through the telephoto end, and the interval between the fifth lens group G5 and the sixth lens group G6 increases.

[0089] While the imaging optical system according to the third embodiment is focusing to make a transition from the infinity in-focus state toward the close-object in-focus state, the fifth lens group G5 moves along the optical axis toward the image plane.

[0090] Meanwhile, the ninth lens L9 and the tenth lens L10 (forming the group of image stabilizer lenses) which belong to the third lens group G3 move perpendicularly to the optical axis to optically compensate for the image blur. These image blur compensation lenses (namely, the ninth lens L9 and the tenth lens L10) allow the imaging optical system to compensate for the shift of the image point due to the vibration of the overall system. That is to say, this allows the imaging optical system to optically compensate for the image blur due to camera shake, vibrations, and other disturbances.

Fourth Embodiment

[0091] FIG. 4A illustrates an imaging optical system according to a fourth embodiment.

[0092] The imaging optical system includes: a first lens group G1 having positive power; a second lens group G2 having negative power; a third lens group G3 having positive power; a fourth lens group G4 having positive power; a fifth lens group G5 having negative power; a sixth lens group G6 having negative power; and a seventh lens group G7 having negative power. The first, second, third, fourth, fifth, sixth, and seventh lens groups G1, G2, G3, G4, G5, G6, G7 are arranged in this order such that the first lens group G1 is located closer to an object than any of the second, third, fourth, fifth, sixth, or seventh lens group G2, G3, G4, G5, G6, G7 is and that the seventh lens group G7 is located closer to an image plane than any of the first, second, third, fourth, fifth, or sixth lens group G1, G2, G3, G4, G5, G6 is.

[0093] The imaging optical system forms an image at a point on the image plane S.

[0094] The first lens group G1 is made up of: a first lens L1 having negative power; a second lens L2 having positive power; and a third lens L3 having positive power. The first lens L1, the second lens L2, and the third lens L3 are arranged in this order such that the first lens L1 is located closer to the object than any other member of this first lens group G1 is and that the third lens L3 is located closer to the image plane than any other member of this first lens group G1 is. The first lens L1 and the second lens L2 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the first lens L1 and the second lens L2.

[0095] The second lens group G2 is made up of: a fourth lens L4 having negative power; a fifth lens L5 having negative power; a sixth lens L6 having positive power; and a seventh lens L7 having negative power. The fourth, fifth, sixth, and seventh lenses L4, L5, L6, L7 are arranged in this order such that the fourth lens L4 is located closer to the object than any other member of this second lens group G2 is and that the seventh lens L7 is located closer to the image plane than any other member of this second lens group G2 is. The fifth lens L5 and the sixth lens L6 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifth lens L5 and the sixth lens L6.

[0096] The third lens group G3 is made up of: an aperture stop A; an eighth lens L8 having positive power; a ninth lens L9 having negative power; a tenth lens L10 having positive power; and an eleventh lens L11 having negative power. The aperture stop A and the eighth, ninth, tenth, and eleventh lenses L8, L9, L10, L11 are arranged in this order such that the aperture stop A is located closer to the object than any other member of this third lens group G3 is and that the eleventh lens L11 is located closer to the image plane than any other member of this third lens group G3 is. The ninth lens L9 and the tenth lens L10 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the ninth lens L9 and the tenth lens L10.

[0097] The fourth lens group G4 is made up of a twelfth lens L12 having positive power and a thirteenth lens L13 having positive power. The twelfth lens L12 is located closer to the object than the thirteenth lens L13 is. The thirteenth lens L13 is located closer to the image plane than the twelfth lens L12 is.

[0098] The fifth lens group G5 is made up of: a fourteenth lens L14 having positive power; and a fifteenth lens L5 having negative power. The fourteenth lens L14 is located closer to the object than the fifteenth lens L15 is. The fifteenth lens L15 is located closer to the image plane than the fourteenth lens L14 is. The fourteenth lens L14 and the fifteenth lens L15 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fourteenth lens L14 and the fifteenth lens L15.

[0099] The sixth lens group G6 is made up of a sixteenth lens L16 having negative power and a seventeenth lens L17 having positive power. The sixteenth lens L16 is located closer to the object than the seventeenth lens L17 is. The seventeenth lens L17 is located closer to the image plane than the sixteenth lens L16 is.

[0100] The seventh lens group G7 consists of an eighteenth lens L18 having negative power.

[0101] The respective lenses will be described.

[0102] First, the respective lenses that form the first lens group G1 will be described. The first lens L1 is a meniscus lens having a convex surface facing the object. The second lens L2 is a biconvex lens. The third lens L3 is a meniscus lens having a convex surface facing the object.

[0103] Next, the respective lenses that form the second lens group G2 will be described. The fourth lens L4 is a meniscus lens having a convex surface facing the object. The fifth lens L5 is a biconcave lens. The sixth lens L6 is a biconvex lens. The seventh lens L7 is a biconcave lens.

[0104] Next, the respective lenses that form the third lens group G3 will be described. The eighth lens L8 is a biconvex lens. The ninth lens L9 is a meniscus lens having a convex surface facing the object. The tenth lens L10 is a biconvex lens. The eleventh lens L11 is a biconcave lens. In this case, the eighth lens L8 is an example of the lens LG3F1. The eighth lens L8 is an example of the group of fixed lenses G3Obj configured not to move perpendicularly to the optical axis during image stabilization. The ninth lens L9 is an example of the lens LG3F2. The ninth lens L9 and the tenth lens L10 are an example of a group of image stabilizer lenses that move perpendicularly to the optical axis during the image stabilization. The eleventh lens L11 is an example of the lens LG3R1. The eleventh lens L11 is an example of a group of fixed lenses G3Img that does not move perpendicularly to the optical axis during the image stabilization.

[0105] Next, the respective lenses that form the fourth lens group G4 will be described. The twelfth lens L12 is a biconvex lens. The thirteenth lens L13 is a biconvex lens. The object-side and image-side surfaces of the thirteenth lens L13 are aspheric surfaces. In this case, the twelfth lens L12 is an example of the lens LG4F1. The twelfth lens L12 is an example of the lens LG4Fp1. The thirteenth lens L13 is an example of the lens LG4F2.

[0106] Next, the respective lenses that form the fifth lens group G5 will be described. The fourteenth lens L14 is a biconvex lens. The fifteenth lens L15 is a biconcave lens.

[0107] Next, the respective lenses that form the sixth lens group G6 will be described. The sixteenth lens L16 is a meniscus lens having a convex surface facing the image plane. The seventeenth lens L17 is a biconvex lens.

[0108] Next, the lens that forms the seventh lens group G7 will be described. The eighteenth lens L18 is a meniscus lens having a convex surface facing the image plane.

[0109] While the imaging optical system according to the fourth embodiment is zooming from the wide-angle end toward the telephoto end during a shooting session, the first lens group G1, the second lens group G2, the third lens group G3, the fourth lens group G4, the fifth lens group G5, the sixth lens group G6, and the seventh lens group G7 all move toward the object with respect to the image plane S. In the meantime, as the imaging optical system is zooming, the first, second, third, fourth, fifth, sixth, and seventh lens groups G1, G2, G3, G4, G5, G6, G7 move along the optical axis such that the interval between the first lens group G1 and the second lens group G2 increases, the interval between the second lens group G2 and the third lens group G3 decreases, the interval between the third lens group G3 and the fourth lens group G4 decreases, the interval between the fourth lens group G4 and the fifth lens group G5 increases from the wide-angle end through a middle position but decreases from the middle position through the telephoto end, the interval between the fifth lens group G5 and the sixth lens group G6 decreases from the wide-angle end through the middle position but increases from the middle position through the telephoto end, and the interval between the sixth lens group G6 and the seventh lens group G7 increases from the wide-angle end through the middle position but decreases from the middle position through the telephoto end.

[0110] While the imaging optical system according to the fourth embodiment is focusing to make a transition from the infinity in-focus state toward the close-object in-focus state, the fifth lens group G5 moves along the optical axis toward the image plane.

[0111] Meanwhile, the ninth lens L9 and the tenth lens L10 (forming the group of image stabilizer lenses) which belong to the third lens group G3 move perpendicularly to the optical axis to optically compensate for the image blur. These image blur compensation lenses (namely, the ninth lens L9 and the tenth lens L10) allow the imaging optical system to compensate for the shift of the image point due to the vibration of the overall system. That is to say, this allows the imaging optical system to optically compensate for the image blur due to camera shake, vibrations, and other disturbances.

Fifth Embodiment

[0112] FIG. 5A illustrates an imaging optical system according to a fifth embodiment.

[0113] The imaging optical system includes: a first lens group G1 having positive power; a second lens group G2 having negative power; a third lens group G3 having positive power; a fourth lens group G4 having positive power; a fifth lens group G5 having negative power; and a sixth lens group G6 having negative power. The first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 are arranged in this order such that the first lens group G1 is located closer to an object than any of the second, third, fourth, fifth, or sixth lens group G2, G3, G4, G5, G6 is and that the sixth lens group G6 is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group G1, G2, G3, G4, G5 is.

[0114] The imaging optical system forms an image at a point on the image plane S.

[0115] The first lens group G1 is made up of: a first lens L1 having negative power; a second lens L2 having positive power; and a third lens L3 having positive power. The first lens L1, the second lens L2, and the third lens L3 are arranged in this order such that the first lens L1 is located closer to the object than any other member of this first lens group G1 is and that the third lens L3 is located closer to the image plane than any other member of this first lens group G1 is. The first lens L1 and the second lens L2 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the first lens L1 and the second lens L2.

[0116] The second lens group G2 is made up of: a fourth lens L4 having negative power; a fifth lens L5 having negative power; a sixth lens L6 having positive power; and a seventh lens L7 having negative power. The fourth, fifth, sixth, and seventh lenses L4, L5, L6, L7 are arranged in this order such that the fourth lens L4 is located closer to the object than any other member of this second lens group G2 is and that the seventh lens L7 is located closer to the image plane than any other member of this second lens group G2 is. The fifth lens L5 and the sixth lens L6 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifth lens L5 and the sixth lens L6.

[0117] The third lens group G3 is made up of: an aperture stop A; an eighth lens L8 having positive power; a ninth lens L9 having negative power; a tenth lens L10 having positive power; and an eleventh lens L11 having negative power. The aperture stop A and the eighth, ninth, tenth, and eleventh lenses L8, L9, L10, L11 are arranged in this order such that the aperture stop A is located closer to the object than any other member of this third lens group G3 is and that the eleventh lens L11 is located closer to the image plane than any other member of this third lens group G3 is. The ninth lens L9 and the tenth lens L10 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the ninth lens L9 and the tenth lens L10.

[0118] The fourth lens group G4 is made up of a twelfth lens L12 having positive power, a thirteenth lens L13 having positive power, and a fourteenth lens L14 having positive power. The twelfth lens L12 is located closer to the object than the thirteenth lens L13 or the fourteenth lens L14 is. The fourteenth lens L14 is located closer to the image plane than the twelfth lens L12 or the thirteenth lens L13 is.

[0119] The fifth lens group G5 is made up of: a fifteenth lens L15 having positive power; and a sixteenth lens L16 having negative power. The fifteenth lens L15 is located closer to the object than the sixteenth lens L16 is. The sixteenth lens L16 is located closer to the image plane than the fifteenth lens L15 is. The fifteenth lens L15 and the sixteenth lens L16 are bonded together with an adhesive, for example, to form a bonded lens. That is to say, the bonded lens includes the fifteenth lens L15 and the sixteenth lens L16.

[0120] The sixth lens group G6 is made up of a seventeenth lens L17 having negative power and an eighteenth lens L18 having positive power. The seventeenth lens L17 is located closer to the object than the eighteenth lens L18 is. The eighteenth lens L18 is located closer to the image plane than the seventeenth lens L17 is.

[0121] The respective lenses will be described.

[0122] First, the respective lenses that form the first lens group G1 will be described. The first lens L1 is a meniscus lens having a convex surface facing the object. The second lens L2 is a biconvex lens. The third lens L3 is a meniscus lens having a convex surface facing the object.

[0123] Next, the respective lenses that form the second lens group G2 will be described. The fourth lens L4 is a meniscus lens having a convex surface facing the object. The fifth lens L5 is a biconcave lens. The sixth lens L6 is a biconvex lens. The seventh lens L7 is a biconcave lens.

[0124] Next, the respective lenses that form the third lens group G3 will be described. The eighth lens L8 is a biconvex lens. The ninth lens L9 is a meniscus lens having a convex surface facing the object. The tenth lens L10 is a biconvex lens. The eleventh lens L11 is a biconcave lens. In this case, the eighth lens L8 is an example of the lens LG3F1. The eighth lens L8 is an example of the group of fixed lenses G3Obj configured not to move perpendicularly to the optical axis during image stabilization. The ninth lens L9 is an example of the lens LG3F2. The ninth lens L9 and the tenth lens L10 are an example of a group of image stabilizer lenses that move perpendicularly to the optical axis during the image stabilization. The eleventh lens L11 is an example of the lens LG3R1. The eleventh lens L11 is an example of a group of fixed lenses G3Img that does not move perpendicularly to the optical axis during the image stabilization.

[0125] Next, the respective lenses that form the fourth lens group G4 will be described. The twelfth lens L12 is a meniscus lens having a convex surface facing the object. The thirteenth lens L13 is a meniscus lens having a convex surface facing the image plane. The fourteenth lens L14 is a biconvex lens. The object-side and image-side surfaces of the fourteenth lens L14 are aspheric surfaces. In this case, the twelfth lens L12 is an example of the lens LG4F1. The twelfth lens L12 is an example of the lens LG4Fp1. The thirteenth lens L13 is an example of the lens LG4F2.

[0126] Next, the respective lenses that form the fifth lens group G5 will be described. The fifteenth lens L15 is a biconvex lens. The sixteenth lens L16 is a biconcave lens.

[0127] Next, the respective lenses that form the sixth lens group G6 will be described. The seventeenth lens L17 is a meniscus lens having a convex surface facing the image plane. The eighteenth lens L18 is a biconvex lens.

[0128] While the imaging optical system according to the fifth embodiment is zooming from the wide-angle end toward the telephoto end during a shooting session, the first lens group G1, the second lens group G2, the third lens group G3, the fourth lens group G4, the fifth lens group G5, and the sixth lens group G6 all move toward the object with respect to the image plane S. In the meantime, as the imaging optical system is zooming, the first, second, third, fourth, fifth, and sixth lens groups G1, G2, G3, G4, G5, G6 move along the optical axis such that the interval between the first lens group G1 and the second lens group G2 increases, the interval between the second lens group G2 and the third lens group G3 decreases, the interval between the third lens group G3 and the fourth lens group G4 decreases, the interval between the fourth lens group G4 and the fifth lens group G5 increases, and the interval between the fifth lens group G5 and the sixth lens group G6 increases.

[0129] While the imaging optical system according to the fifth embodiment is focusing to make a transition from the infinity in-focus state toward the close-object in-focus state, the fifth lens group G5 moves along the optical axis toward the image plane.

[0130] Meanwhile, the ninth lens L9 and the tenth lens L10 (forming the group of image stabilizer lenses) which belong to the third lens group **G3** move perpendicularly to the optical axis to optically compensate for the image blur. These image blur compensation lenses (namely, the ninth lens **L9** and the tenth lens **L10**) allow the imaging optical system to compensate for the shift of the image point due to the vibration of the overall system. That is to say, this allows the imaging optical system to optically compensate for the image blur due to camera shake, vibrations, and other disturbances.

Other Embodiments

[0131] The first, second, third, fourth, and fifth embodiments have been described as exemplary embodiments of the present disclosure. Note that the embodiments described above are only examples of the present disclosure and should not be construed as limiting. Rather, each of these embodiments may be readily modified, replaced, combined with other embodiments, provided with some additional components, or partially omitted without departing from the scope of the present disclosure.

[0132] For example, in the first to fifth embodiments described above, the imaging optical system is supposed to be used in the entire zoom range from the wide-angle end through the telephoto end. However, the imaging optical system does not have to be used in the entire zoom range. Alternatively, the imaging optical system may also be used selectively only in an extracted range where optical performance is ensured according to the desired zoom range, for example. That is to say, the imaging optical system may also be used as an imaging optical system with lower zoom power than the imaging optical system to be described for the first, second, third, fourth, and fifth examples of numerical values corresponding to the first, second, third, fourth, and fifth embodiments, respectively. Optionally, the imaging optical system may also be used selectively as a single-focus lens system only at an extracted focal length where optical performance is ensured according to the desired zoom position.

[0133] In addition, the number of the lens groups and the number of the lenses that form each lens group are substantial numbers. Optionally, a lens having substantially no power may be added to any of the lens groups described above.

[0134] In the embodiments described above, the image blur is compensated for by moving the image blur compensation lenses perpendicularly to the optical axis. However, the image blur may be compensated for as long as the lenses are moved such that each of those lenses has a vertical direction component. For example, the image blur may also be compensated for by pivoting the image blur compensation lenses around a center of rotation on the optical axis (i.e., with the lenses tilted such that the axis of each of these lenses intersects with the optical axis of the imaging optical system) if the lens barrel is allowed to have a complicated structure.

(Conditions and Advantages)

[0135] Next, conditions that may be satisfied by the imaging optical systems according to the first to fifth embodiments, for example, will be described. A plurality of possible conditions may be defined for the imaging optical system according to each of the first to fifth embodiments. In that case, an imaging optical system, of which the configuration satisfies all of these possible conditions, is most advantageous. Alternatively, an imaging optical system that achieves its expected advantages by satisfying any of the individual conditions to be described below may also be provided.

[0136] An imaging optical system according to each of the first to fifth embodiments described above includes: a first lens group having positive power; a second lens group having negative power; a third lens group having positive power; a fourth lens group having positive power; a fifth lens group having negative power; and a sixth lens group having power. The first, second, third, fourth, fifth, and sixth lens groups are arranged in this order such that the first lens group is located closer to an object than any of the second, third, fourth, fifth or sixth lens group is, and that the sixth lens group is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group is. An interval between each pair of lens groups that are adjacent to each other changes as at least the first, second, third, fourth, fifth, and sixth lens groups move in an optical axis direction while the imaging optical system is zooming. The optical axis direction is a direction aligned with an optical axis of the imaging optical system. This configuration will be hereinafter referred to as a "basic configuration."

[0137] The imaging optical system with the basic configuration has a configuration that may be used effectively to reduce the overall size of the zoom lens. This allows the imaging optical system to compensate for various types of aberrations that occur to the respective lens groups during zooming. Consequently, this allows for providing an imaging optical system having the ability to compensate for various types of aberrations sufficiently over the entire zoom range.

[0138] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization; and a group of fixed lenses G**3**Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization.

[0139] The imaging optical system preferably satisfies the following inequality (1):

$$0.06 < Th\_IS\_Obj/Th\_G3 < 0.50 \tag{1}$$

[0140] where Th_IS_Obj is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G**3**Obj, and

[0141] Th_G**3** is the thickness of the third lens group **G3** on the optical axis.

[0142] The condition expressed by this inequality (1) defines the ratio of an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G**3**Obj to the thickness of the third lens group **G3** on the optical axis (i.e., a thickness measured on the optical axis from the object-side surface of a lens located closer to the object than any other lens belonging to the third lens group **G3** is to the image-side surface of a lens located closer to the image plane than any other lens belonging to the third lens group **G3** is).

[0143] If the Th_IS_Obj/Th_G3 ratio were less than the lower limit set by the inequality (1), then the spherical aberration would be too positively biased (i.e., toward the positive side of the spherical aberration diagram to be referred to later) over the entire zoom range and the image plane would be too negatively biased (i.e., toward the negative side of the spherical aberration diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0144] Conversely, if the Th_IS_Obj/Th_G3 ratio were greater than the upper limit set by the inequality (1), then the spherical aberration would be too negatively biased over the entire zoom range and the image plane would be too positively biased over the entire zoom range, which is not beneficial, either.

[0145] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (1a) and (1b) is/are preferably satisfied:

$$0.08 < Th\_IS\_Obj/Th\_G3 \tag{1a}$$

$$Th\_IS\_Obj/Th\_G3 < 0.30. \tag{1b}$$

[0146] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (1c) and (1d) is/are satisfied:

$$0.10 < Th\_IS\_Obj/Th\_G3 \tag{1c}$$

$$Th\_IS\_Obj/Th\_G3 < 0.25. \tag{1d}$$

[0147] Even more preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (1) and (1f) is/are satisfied:

$$0.12 < Th\_IS\_Obj/Th\_G3 \tag{1e}$$

$$Th\_IS\_Obj/Th\_G3 < 0.20. \tag{1f}$$

[0148] For example, in the imaging optical system, the fourth lens group **G4** preferably includes at least two lenses.

[0149] The imaging optical system preferably satisfies the following inequality (2):

$$0.05 < Th\_G4\_Air/Th\_G4 < 0.80 \tag{2}$$

where Th_**G4** Air is a maximum value of an air gap on the optical axis between adjacent lenses included in at least two lenses that form the fourth lens group **G4**; and

[0150] Th_**G4** is the thickness of the fourth lens group **G4** on the optical axis.

[0151] The condition expressed by the inequality (2) defines the ratio of a maximum value of an air gap between adjacent lenses included in at least two lenses which form part of the fourth lens group **G4** to the thickness of the fourth lens group **G4** on the optical axis.

[0152] If the Th_**G4**_Air/Th_**G4** ratio were less than the lower limit set by the inequality (2), then the spherical aberration would be too positively biased (i.e., toward the positive side of the spherical aberration diagram to be referred to later) on the telephoto side and the image plane would be too negatively biased (i.e., toward the negative side of the spherical aberration diagram to be referred to later) on the telephoto side, which is not beneficial.

[0153] Conversely, if the Th_**G4**_Air/Th_**G4** ratio were greater than the upper limit set by the inequality (2), then the spherical aberration would be too negatively biased on the telephoto side and the image plane would be too positively biased on the telephoto side, which is not beneficial, either.

[0154] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (2a) and (2b) is/are preferably satisfied:

$$0.075 < Th\_G4\_Air/Th\_G4 \tag{2a}$$

$$Th\_G4\_Air/Th\_G4 < 0.700. \tag{2b}$$

[0155] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (2c) and (2d) is/are satisfied:

$$0.100 < Th\_G4\_Air/Th\_G4 \tag{2c}$$

$$Th\_G4\_Air/Th\_G4 < 0.600. \tag{2d}$$

[0156] Even more preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (2e) and (2f) is/are satisfied:

$$0.150 < Th\_G4\_Air/Th\_G4 \tag{2e}$$

$$Th\_G4\_Air/Th\_G4 < 0.500. \tag{2f}$$

[0157] Particularly preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (2g) and (2h) is/are satisfied:

$$0.190 < Th\_G4\_Air/Th\_G4 \tag{2g}$$

$$Th\_G4\_Air/Th\_G4 < 0.400. \tag{2h}$$

[0158] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization; a group of fixed lenses **G3**Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during an image stabilization; and a group of fixed lenses **G3**Img located closer to the image plane than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization.

[0159] This may reduce the chances of the group of image stabilizer lenses moving during the image stabilization. Consequently, the aberrations may be compensated for sufficiently even when the group of image stabilizer lenses moves perpendicularly to the optical axis.

[0160] For example, in the imaging optical system, an object-side surface of a lens **LG3R1** located closer to the image plane than any of other negative lenses that form part of the third lens group **G3** preferably has a convex surface facing the image plane.

[0161] This allows the spherical aberration occurring in the third lens group **G3** having positive power to be compensated for sufficiently over the entire zoom range.

[0162] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization; and a group of fixed lenses **G3**Img located closer to the image plane than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis.

[0163] The imaging optical system preferably satisfies the following inequality (3):

$$0.05 < Th\_IS\_Img/Th\_G3 < 0.80 \tag{3}$$

where Th_IS_Img is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses **G3**Img, and

[0164] Th **G3** is the thickness of the third lens group **G3** on the optical axis.

[0165] The condition expressed by the inequality (3) defines the ratio of an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses **G3**Img to the thickness of the third lens group **G3** on the optical axis (i.e., a thickness measured on the optical axis from the object-side surface of a lens located closer to the object than any other lens belonging to the third lens group **G3** is to the image-side surface of a lens located closer to the image plane than any other lens belonging to the third lens group **G3** is).

[0166] If the Th_IS_Img/Th_**G3** ratio were less than the lower limit set by the inequality (3), then the spherical aberration would be too positively biased (i.e., toward the positive side of the spherical aberration diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0167] Conversely, if the Th_IS_Img/Th_**G3** ratio were greater than the upper limit set by the inequality (3), then the spherical aberration would be too negatively biased (i.e., toward the negative side of the spherical aberration diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0168] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (3a) and (3b) is/are preferably satisfied:

$$0.075 < Th\_IS\_Img/Th\_G3 \tag{3a}$$

$$Th\_IS\_Img/Th\_G3 < 0.400. \tag{3b}$$

[0169] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (3c) and (3d) is/are satisfied:

$$0.120 < Th\_IS\_Img/Th\_G3 \tag{3c}$$

$$Th\_IS\_Img/Th\_G3 < 0.200. \tag{3d}$$

[0170] For example, the imaging optical system preferably satisfies the following inequality (4):

$$0.0 < (R2\_LG3F1 + R1\_LG3F2)/(R2\_LG3F1 - R1\_LG3F2) < 1.0 \tag{4}$$

where **R2_LG3F1** is a radius of curvature of an image-side surface of a lens **LG3F1** located closer to the object than any other lens belonging to the third lens group **G3** is, and

[0171] **R1_LG3F2** is a radius of curvature of an object-side surface of a lens **LG3F2** located adjacent to the lens **LG3F1** and closer to the image plane than the lens **LG3F1** is.

[0172] The condition expressed by the inequality (4) defines the ratio of the sum of a radius of curvature of an image-side surface of a lens **LG3F1** located closer to the object than any other lens belonging to the third lens group and a radius of curvature of an object-side surface of a lens **LG3F2** located adjacent to the lens **LG3F1** and closer to the image plane than the lens **LG3F1** is to the difference between the former and latter radii of curvature.

[0173] If the ratio were less than the lower limit set by the inequality (4), then the spherical aberration would be too positively biased (i.e., toward the positive side of the spherical aberration diagram to be referred to later) on the telephoto side, which is not beneficial. In addition, the image plane would be too positively biased (i.e., toward the positive side of the spherical aberration diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0174] Conversely, if the ratio were greater than the upper limit set by the inequality (4), then the spherical aberration would be too negatively biased (i.e., toward the negative side of the spherical aberration diagram to be referred to later) on the telephoto side, which is not beneficial. In addition, the image plane would be too negatively biased (i.e., toward the negative side of the spherical aberration diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0175] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (4a) and (4b) is/are preferably satisfied:

$$(R2\_LG3F1 + R1\_LG3F2)/(R2\_LG3F1 - R1\_LG3F2) < 0.97 \tag{4a}$$

$$0.65 < (R2\_LG3F1 + R1\_LG3F2)/(R2\_LG3F1 - R1\_LG3F2). \tag{4b}$$

[0176] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (4c) and (4d) is/are satisfied:

$$(R2\_LG3F1+R1\_LG3F2)/(R2\_LG3F1-R1\_LG3F2)<0.95 \tag{4c}$$

$$0.80<(R2\_LG3F1+R1\_LG3F2)/(R2\_LG3F1-R1\_LG3F2). \tag{4d}$$

[0177] For example, in the imaging optical system, an image-side surface of a positive lens LG**4**Fp**1** located closer to the object than any other lens belonging to the fourth lens group **G4** is preferably has a convex surface facing the object.

[0178] This allows the planarity of the image plane S to be corrected sufficiently over the entire zoom range.

[0179] For example, the imaging optical system preferably satisfies the following inequality (5):

$$-10.0<(R2\_LG4F1+R1\_LG4F2)/(R2\_LG4F1-R1\_LG4F2)<1.0 \tag{5}$$

where **R2_LG4F1** is a radius of curvature of an image-side surface of a lens **LG4F1** located closer to the object than any other lens belonging to the fourth lens group **G4** is, and

[0180] **R1_LG4F2** is a radius of curvature of an object-side surface of a lens **LG4F2** located adjacent to the lens **LG4F1** and closer to the image plane than the lens **LG4F1** is.

[0181] The condition expressed by the inequality (5) defines the ratio of the sum of a radius of curvature of an image-side surface of a lens **LG4F1** located closer to the object than any other lens belonging to the fourth lens group **G4** is and a radius of curvature of an object-side surface of a lens **LG4F2** located adjacent to the lens **LG4F1** and closer to the image plane than the lens **LG4F1** is to the difference between the former and latter radii of curvature.

[0182] If the ratio were less than the lower limit set by the inequality (5), then the image plane would be too negatively biased (i.e., toward the negative side of the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0183] Conversely, if the ratio were greater than the upper limit set by the inequality (5), then the image plane would be too positively biased (i.e., toward the positive side of the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0184] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (5a) and (5b) is/are preferably satisfied:

$$(R2\_LG4F1+R1\_LG4F2)/(R2\_LG4F1-R1\_LG4F2)<0.75 \tag{5a}$$

$$-8.0<(R2\_LG4F1+R1\_LG4F2)/(R2\_LG4F1-R1\_LG4F2). \tag{5b}$$

[0185] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (5c) and (5d) is/are satisfied:

$$(R2\_LG4F1+R1\_LG4F2)/(R2\_LG4F1-R1\_LG4F2)<0.50 \tag{5c}$$

$$-6.0<(R2\_LG4F1+R1\_LG4F2)/(R2\_LG4F1-R1\_LG4F2). \tag{5d}$$

[0186] For example, the imaging optical system preferably satisfies the following inequality (6):

$$nd\_LG4Fp1<1.6 \tag{6}$$

where nd_**LG4Fp1** is a refractive index of a positive lens **LG4Fp1** located closer to the object than any other lens belonging to the fourth lens group **G4** is.

[0187] The condition expressed by the inequality (6) defines the refractive index of a positive lens **LG4Fp1** located closer to the object than any other lens belonging to the fourth lens group **G4** is.

[0188] If the refractive index were greater than the upper limit set by the inequality (6), then the spherical aberration would be too positively biased (i.e., toward the positive side of the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0189] To enhance the advantage described above, the condition expressed by the following inequality (6a) is preferably satisfied:

$$nd\_LG4Fp1<1.55. \tag{6a}$$

[0190] More preferably, to further enhance the advantage described above, the imaging optical system satisfies the condition expressed by the following inequality (6b):

$$1.40<nd\_LG4Fp1. \tag{6b}$$

[0191] If the refractive index were less than the lower limit set by the inequality (6b), then the spherical aberration might be too negatively biased (i.e., toward the negative side of the astigmatism diagram to be referred to later).

[0192] For example, in the imaging optical system, the fifth lens group **G5** is preferably configured to move toward the image plane while the imaging optical system is focusing from an infinity in-focus object toward a close-object in-focus state.

[0193] This ensures good focus performance while the imaging optical system is focusing.

[0194] For example, the imaging optical system preferably satisfies the following inequality (7):

$$0.1<ThwG5\_G6/fw<0.8 \tag{7}$$

where ThwG**5**_**G6** is an interval measured on the optical axis between the fifth lens group **G5** and the sixth lens group **G6** in the imaging optical system at a wide-angle end; and

[0195] fw is a focal length of the imaging optical system at the wide-angle end.

[0196] The condition expressed by the inequality (7) defines the ratio of an interval measured on the optical axis between the fifth lens group **G5** and the sixth lens group **G6** in the imaging optical system at a wide-angle end to a focal length of the imaging optical system at the wide-angle end.

[0197] If the ThwG**5**_G**6**/fw ratio were less than the lower limit set by the inequality (7), the magnitude of movement of the fifth lens group **G5** toward the image plane while the imaging optical system is focusing from the infinity in-focus state toward the close-object in-focus state would decrease to the point of causing a decline in focusing accuracy, which is not beneficial.

[0198] Conversely, if the ThwG**5**_G**6**/fw ratio were greater than the upper limit set by the inequality (7), the magnitude of movement of the fifth lens group **G5** toward the image plane while the imaging optical system is focusing from the infinity in-focus state toward the close-object in-focus state would increase to the point of making the total optical length too long, which is not beneficial, either.

[0199] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (7a) and (7b) is/are preferably satisfied:

$$0.20 < \mathrm{ThwG5\_G6}/fw \tag{7a}$$

$$\mathrm{ThwG5\_G6}/fw < 0.70. \tag{7b}$$

[0200] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (7c) and (7d) is/are satisfied:

$$0.32 < \mathrm{ThwG5\_G6}/fw \tag{7c}$$

$$\mathrm{ThwG5\_G6}/fw < 0.60. \tag{7d}$$

[0201] For example, the imaging optical system preferably satisfies the following inequality (8):

$$0.2 < fG1/fT < 1.0 \tag{8}$$

where fG**1** is a focal length of the first lens group **G1**, and

[0202] fT is a focal length of the imaging optical system at a telephoto end.

[0203] The condition expressed by the inequality (8) defines the ratio of a focal length of the first lens group **G1** to a focal length of the imaging optical system at a telephoto end.

[0204] If the fG**1**/fT ratio were less than the lower limit set by the inequality (8), then the focal length of the first lens group **G1** would be so short as to make it difficult to increase the focal length of the imaging optical system at the telephoto end, which is not beneficial.

[0205] Conversely, if the fG**1**/fT ratio were greater than the upper limit set by the inequality (8), then the focal length of the first lens group **G1** would be so long as to make the magnitude of movement of the first lens group **G1** too much while the imaging optical system is zooming, which is not beneficial, either.

[0206] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (8a) and (8b) is/are preferably satisfied:

$$0.25 < fG1/fT \tag{8a}$$

$$fG1/fT < 0.80. \tag{8b}$$

[0207] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (8c) and (8d) is/are satisfied:

$$0.30 < fG1/fT \tag{8c}$$

$$fG1/fT < 0.50. \tag{8d}$$

[0208] The imaging optical system preferably satisfies the following inequality (9):

$$-2.5 < fG5/fw < -1.0 \tag{9}$$

where fG**5** is a focal length of the fifth lens group **G5**, and

[0209] fw is a focal length of the imaging optical system at a wide-angle end.

[0210] The condition set by the inequality (9) defines the ratio of a focal length of the fifth lens group **G5** to a focal length of the imaging optical system at a wide-angle end.

[0211] If the fG**5**/fw ratio were less than the lower limit set by the inequality (9), then the focal length of the fifth lens group **G5** would be so short as to make it difficult to reduce the variation in aberration from the wide-angle end through the telephoto end while the imaging optical system is zooming, which is not beneficial.

[0212] Conversely, if the fG**5**/fw ratio were greater than the upper limit set by the inequality (9), then the focal length of the fifth lens group **G5** would be so long as to make the magnitude of movement too much while the imaging optical system is focusing, which is not beneficial, either.

[0213] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (9a) and (9b) is/are preferably satisfied:

$$-2.25 < fG5/fw \tag{9a}$$

$$fG5/fw < -1.50. \tag{9b}$$

[0214] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (9c) and (9d) is/are satisfied:

$$-1.90 < fG5/fw \tag{9c}$$

$$fG5/fw < -1.80. \tag{9d}$$

[0215] For example, the imaging optical system preferably satisfies the following inequality (10):

$$0.5 < \mathrm{Th\_G2\_G3}/Yw < 3.0 \tag{10}$$

where Th_G2_G3 is an air gap measured on the optical axis between the second lens group G2 and the third lens group G3 in the imaging optical system at a wide-angle end, and

[0216] Yw is a maximum image height of the imaging optical system at the wide-angle end.

[0217] The condition expressed by the inequality (10) defines the ratio of an air gap measured on the optical axis between the second lens group G2 and the third lens group G3 in the imaging optical system at a wide-angle end (i.e., the gap measured on the optical axis between an image-side surface of a lens located closer to the image plane than any other lens belonging to the second lens group G2 to an object-side surface of lens located closer to the object than any other lens belonging to the third lens group G3) to a maximum image height of the imaging optical system at the wide-angle end. In a camera system or an image capture device including an imaging optical system, the maximum image height of the imaging optical system at the wide-angle end may be regarded as a diagonal length, measured on an image sensor, of an imaging point corresponding to the angle of view at the wide-angle end.

[0218] If the Th_G2_G3/Yw ratio were less than the lower limit set by the inequality (10), then the interval would change so little while the imaging optical system is zooming as to make it difficult to compensate for aberrations at the time of zooming, which is not beneficial.

[0219] Conversely, if the Th_G2_G3/Yw ratio were greater than the upper limit set by the inequality (10), then the interval would change so much while the imaging optical system is zooming as to make it difficult to arrange a mechanism for causing either the second lens group G2 or the third lens group G3 to move, which is not beneficial, either.

[0220] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (10a) and (10b) is/are preferably satisfied:

$$0.75 < \mathrm{Th\_G2\_G3}/Yw \tag{10a}$$

$$\mathrm{Th\_G2\_G3}/Yw < 2.00. \tag{10b}$$

[0221] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (10c) and (10d) is/are satisfied:

$$0.85 < \mathrm{Th\_G2\_G3}/Yw \tag{10c}$$

$$\mathrm{Th\_G2\_G3}/Yw < 1.00. \tag{10d}$$

[0222] For example, the imaging optical system preferably satisfies the following inequality (11):

$$0.3 < BFw/Yw < 3.0 \tag{11}$$

where BFw is a back focus of the imaging optical system at a wide-angle end; and

[0223] Yw is a maximum image height of the imaging optical system at the wide-angle end.

[0224] The condition expressed by the inequality (11) defines the ratio of a back focus of the imaging optical system at a wide-angle end (i.e., the interval measured on the optical axis from a lens located closest to the image plane to the image plane S in the imaging optical system at a wide-angle end) to a maximum image height of the imaging optical system at the wide-angle end. In a camera system or an image capture device including an imaging optical system, the maximum image height of the imaging optical system at the wide-angle end may be regarded as a diagonal length, measured on an image sensor, of an imaging point corresponding to the angle of view at the wide-angle end.

[0225] If the BFw/Yw ratio were less than the lower limit set by the inequality (11), then the back focus would be so narrow as to make it difficult to arrange a member for use to couple the imaging optical system to an image sensor placed on the image plane S, which is not beneficial.

[0226] Conversely, if the BFw/Yw ratio were greater than the upper limit set by the inequality (11), then the back focus would be so wide as to make the overall size of the imaging optical system too large, which is not beneficial, either.

[0227] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (11a) and (11b) is/are preferably satisfied:

$$0.40 < BFw/Yw \tag{11a}$$

$$BFw/Yw < 2.40. \tag{11b}$$

[0228] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (11c) and (11d) is/are satisfied:

$$0.50 < BFw/Yw \tag{11c}$$

$$BFw/Yw < 1.20. \tag{11d}$$

[0229] Even more preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (11e) and (11f) is/are satisfied:

$$0.75 < BFw/Yw \tag{11e}$$

$$BFw/Yw < 0.90. \tag{11f}$$

[0230] For example, the imaging optical system preferably satisfies the following inequality (12):

$$2.0 < TTLw / Yw < 10.0 \tag{12}$$

where TTLw is a total optical length of the imaging optical system at a wide-angle end; and

[0231] Yw is a maximum image height of the imaging optical system at the wide-angle end.

[0232] The condition expressed by the inequality (12) defines the ratio of a total optical length of the imaging optical system at a wide-angle end (i.e., the interval measured from an object-side surface of a lens located closest to the object to the image plane S in the imaging optical system) to a maximum image height of the imaging optical system at the wide-angle end. In a camera system or an image capture device including an imaging optical system, the maximum image height of the imaging optical system at the wide-angle end may be regarded as a diagonal length, measured on an image sensor, of an imaging point corresponding to the angle of view at the wide-angle end.

[0233] If the TTLw/Yw ratio were less than the lower limit set by the inequality (12), then the total optical length of the imaging optical system at the wide-angle end would be so short as to make it difficult to compensate for aberrations sufficiently, which is not beneficial.

[0234] Conversely, if the TTLw/Yw ratio were greater than the upper limit set by the inequality (12), then the total optical length of the imaging optical system at the wide-angle end would be too long, which is not beneficial, either.

[0235] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (12a) and (12b) is/are preferably satisfied:

$$3.0 < TTLw / Yw \tag{12a}$$

$$TTLw / Yw < 8.0. \tag{12b}$$

[0236] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (12c) and (12d) is/are satisfied:

$$4.0 < TTLw / Yw \tag{12c}$$

$$TTLw / Yw < 5.5. \tag{12d}$$

[0237] For example, the imaging optical system preferably satisfies the following inequality (13):

$$0.1 < (TTLt - TTLw) / TTLt < 0.5 \tag{13}$$

where TTLt is a total optical length of the imaging optical system at a telephoto end; and

[0238] TTLw is a total optical length of the imaging optical system at a wide-angle end.

[0239] The condition expressed by the inequality (13) defines the ratio of the difference between the total optical length of the imaging optical system at the telephoto end and the total optical length of the imaging optical system at the wide-angle end to the total optical length of the imaging optical system at the telephoto end. Note that the total optical length of the imaging optical system is the interval from an object-side surface of a lens located closest to the object in the imaging optical system to the image plane S.

[0240] If the (TTLt−TTLw)/TTLt ratio were less than the lower limit set by the inequality (13), then the total optical length would change so little while the imaging optical system is zooming as to make it difficult to ensure a sufficient zoom ratio, which is not beneficial.

[0241] Conversely, if the (TTLt−TTLw)/TTLt ratio were greater than the upper limit set by the inequality (13), then the total optical length would change so much while the imaging optical system is zooming as to make it difficult to arrange a mechanism for causing the lens groups to move, which is not beneficial, either.

[0242] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (13a) and (13b) is/are preferably satisfied:

$$0.20 < (TTLt - TTLw) / TTLt \tag{13a}$$

$$(TTLt - TTLw) / TTLt < 0.40. \tag{13b}$$

[0243] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (13c) and (13d) is/are satisfied:

$$0.25 < (TTLt - TTLw) / TTLt \tag{13c}$$

$$(TTLt - TTLw) / TTLt < 0.30. \tag{13d}$$

[0244] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses that move perpendicularly to the optical axis during the image stabilization; and a negative lens LG**3***n* that does not move perpendicularly to the optical axis during the image stabilization. In the first to fifth embodiments, the negative lens LG**3***n* may be, for example, the eleventh lens L**11**.

[0245] This allows for reducing the movement of the group of image stabilizer lenses during the image stabilization. This allows, even when the group of image stabilizer lenses moves perpendicularly to the optical axis, the aberrations to be compensated for sufficiently.

[0246] For example, in the imaging optical system, the third lens group **G3** is preferably made up of at least four and at most six lenses.

[0247] This allows, even when the group of image stabilizer lenses moves perpendicularly to the optical axis, the aberrations caused by the group of image stabilizer lenses to be compensated for sufficiently.

[0248] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses that move perpendicularly to the optical axis during the image stabilization; and a group of fixed lenses G**3**Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and not moving perpendicularly to the optical axis during image stabilization.

[0249] The imaging optical system preferably satisfies the following inequality (14):

$$0.01 < Th\_IS\_Obj / Yw < 1.00 \tag{14}$$

where Th_IS_Obj is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G3Obj, and

[0250] Yw is a maximum image height of the imaging optical system at a wide-angle end.

[0251] The condition expressed by the inequality (14) defines the ratio of an air gap on the optical axis between a group of image stabilizer lenses and a group of fixed lenses G3Obj to a maximum image height of the imaging optical system at a wide-angle end. In a camera system or an image capture device including an imaging optical system, the maximum image height of the imaging optical system at the wide-angle end may be regarded as a diagonal length, measured on an image sensor, of an imaging point corresponding to the angle of view at the wide-angle end.

[0252] If the Th_IS_Obj/Yw ratio were less than the lower limit set by the inequality (14), then the spherical aberration would be significantly positively biased (i.e., toward the positive side in the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0253] Conversely, if the Th_IS_Obj/Yw ratio were greater than the upper limit set by the inequality (14), then the spherical aberration would be significantly negatively biased (i.e., toward the negative side in the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0254] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (14a) and (14b) is/are preferably satisfied:

$$0.05 < Th\_IS\_Obj / Yw \tag{14a}$$

$$Th\_IS\_Obj / Yw < 0.75. \tag{14b}$$

[0255] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (14c) and (14d) is/are satisfied:

$$0.08 < Th\_IS\_Obj / Yw \tag{14c}$$

$$Th\_IS\_Obj / Yw < 0.25 \tag{14d}$$

[0256] For example, in the imaging optical system, the third lens group **G3** preferably includes: a group of image stabilizer lenses consisting of a plurality of lenses that move perpendicularly to the optical axis during the image stabilization; and a group of fixed lenses **G3**Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and not moving perpendicularly to the optical axis during image stabilization.

[0257] The imaging optical system preferably satisfies the following inequality (15):

$$0.02 < Th\_IS\_Img / Yw < 1.00 \tag{15}$$

where Th_IS_Img is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G3Img, and

[0258] Yw is a maximum image height of the imaging optical system at a wide-angle end.

[0259] The condition expressed by the inequality (15) defines the ratio of an air gap on the optical axis between a group of image stabilizer lenses and the group of fixed lenses **G3**Img to a maximum image height of the imaging optical system at a wide-angle end. In a camera system or an image capture device including an imaging optical system, the maximum image height of the imaging optical system at the wide-angle end may be regarded as a diagonal length, measured on an image sensor, of an imaging point corresponding to the angle of view at the wide-angle end.

[0260] If the Th_IS_Img/Yw ratio were less than the lower limit set by the inequality (15), then the spherical aberration would be significantly positively biased (i.e., toward the positive side in the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial.

[0261] Conversely, if the Th_IS_Img/Yw ratio were greater than the upper limit set by the inequality (15), then the spherical aberration would be significantly negatively biased (i.e., toward the negative side in the astigmatism diagram to be referred to later) over the entire zoom range, which is not beneficial, either.

[0262] To enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (15a) and (15b) is/are preferably satisfied:

$$0.05 < Th\_IS\_Img / Yw \tag{15a}$$

$$Th\_IS\_Img / Yw < 0.50. \tag{15b}$$

[0263] More preferably, to further enhance the advantage described above, the condition(s) expressed by one or both of the following inequalities (15c) and (15d) is/are satisfied:

$$0.08 < Th\_IS\_Img / Yw \tag{15c}$$

$$Th\_IS\_Img / Yw < 0.15. \tag{15d}$$

[0264] In the first to fifth embodiments described above, an imaging optical system which includes an aperture stop A located closer to the object than any other member of the third lens group **G3** and moving along with the lenses of the third lens group **G3** while the imaging optical system is zooming has been described as an exemplary arrangement in which the third lens group **G3** includes the aperture stop A. However, this is only an example and should not be construed as limiting. Alternatively, the third lens group **G3** may include the aperture stop A located closer to the image plane than any other member of the third lens group **G3** is and moving along with the lenses of the third lens group **G3** while the imaging optical system is zooming. Still alternatively, the second lens group **G2** may include the aperture stop A located closer to the image plane than any other member of the second lens group **G2** is and moving along with the lenses of the second lens group **G2** while the imaging optical system is zooming. Yet alternatively, the aperture stop A may also be provided between the second lens group **G2** and the third lens group **G3** to move independently of the second lens group **G2** and the third lens group **G3** while the imaging optical system is zooming.

[0265] Nevertheless, providing the third lens group **G3** with the aperture stop A located closer to the object than any other member of the third lens group **G3** is and moving along with the lenses of the third lens group **G3** while the imaging optical system is zooming may reduce the chances of the effective diameter of the frontend lens (i.e., the first lens **L1**) increasing too much.

[0266] Optionally, if the complexity of a cam mechanism for use to make zooming is allowable, then controlling the aperture stop A to move independently of the second lens group **G2** and the third lens group **G3** also reduces the chances of the effective diameter of the frontend lens (i.e., the first lens **L1**) increasing too much.

Schematic Configuration for Image Capture Device to which First Embodiment is Applied

[0267] FIG. **6** illustrates a schematic configuration for an image capture device, to which the imaging optical system of the first embodiment is applied. Alternatively, the imaging optical system according to the second, third, fourth, or fifth embodiment is also applicable to the image capture device.

[0268] The image capture device **100** includes a housing **104**, an image sensor **102**, and the imaging optical system **101** according to the first embodiment. Specifically, the image capture device **100** may be implemented as a digital camera, for example.

[0269] The housing **104** includes a lens barrel **302**. The lens barrel **302** holds the respective lens groups and the aperture stop A that form the imaging optical system **101**.

[0270] The image sensor **102** is disposed at the image plane S of the imaging optical system according to the first embodiment.

[0271] In the imaging optical system **101**, the first lens group **G1**, the second lens group **G2**, the third lens group **G3**, the fourth lens group **G4**, the fifth lens group **G5**, and the sixth lens group **G6** are attached to, or engaged with, a lens frame included in the lens barrel **302** so as to move while the imaging optical system **101** is zooming.

[0272] This provides an image capture device with the ability to compensate for various types of aberrations sufficiently.

[0273] In the example described above, the imaging optical system according to the first embodiment is applied to a digital camera. However, this is only an example and should not be construed as limiting. Alternatively, the imaging optical system is also applicable to a surveillance camera, a smartphone, or any of various other types of image capture devices.

Schematic Configuration for Camera System to which First Embodiment is Applied

[0274] FIG. **7** illustrates a schematic configuration for a camera system, to which the imaging optical system of the first embodiment is applied. Alternatively, the imaging optical system according to the second, third, fourth, or fifth embodiment is also applicable to the camera system.

[0275] The camera system **200** includes a camera body **201** and an interchangeable lens unit **300** to be connected removably to the camera body **201**.

[0276] The camera body **201** includes an image sensor **202**, a monitor **203**, a memory, a camera mount **204**, and a viewfinder **205**. The image sensor **202** receives an optical image formed by the imaging optical system **301** of the interchangeable lens unit **300** and transforms the optical image into an electrical image signal. The monitor **203** displays the image signal transformed by the image sensor **202**. The memory stores the image signal.

[0277] The imaging optical system **301** of the interchangeable lens unit **300** is the imaging optical system according to the first embodiment.

[0278] The interchangeable lens unit **300** includes not only the imaging optical system **301** but also a lens barrel **302** and a lens mount **304** as well. The lens barrel **302** holds the respective lens groups and aperture stop A that form the imaging optical system **301**. The lens mount **304** is to be connected to the camera mount **204** of the camera body **201**.

[0279] The camera mount **204** and the lens mount **304** are physically connected together. In addition, the camera mount **204** and the lens mount **304** also electrically connect together a controller in the camera body **201** and a controller in the interchangeable lens unit **300**. That is to say, the camera mount **204** and the lens mount **304** serve as interfaces that allow themselves to exchange signals with each other.

[0280] In the imaging optical system **301**, the first lens group **G1**, the second lens group **G2**, the third lens group **G3**, the fourth lens group **G4**, the fifth lens group **G5**, and the sixth lens group **G6** are attached to, or engaged with, a lens frame included in the lens barrel **302** so as to be movable while the imaging optical system **301** is zooming.

[0281] In the camera system **200** including the respective lens groups held by the lens barrel **302** and the camera body **201**, an actuator, a lens frame, and other members to be controlled by the controller in the interchangeable lens unit **300** are provided such that the fifth lens group **G5** may move while the imaging optical system **301** is focusing.

Examples of Numerical Values

[0282] Next, exemplary sets of specific numerical values that were actually adopted in the imaging optical systems with the configurations according to the first, second, third, fourth, and fifth embodiments will be described. Note that in the tables showing these exemplary sets of numerical values, the length is expressed in millimeters (mm), the angle of view is expressed in degrees (°), r indicates the radius of curvature, d indicates the surface interval, nd indicates a refractive index in response to a d-line, vd (also denoted as "vd") indicates an abbe number in response to a d-line, and a surface with an asterisk (*) is an aspheric surface. The aspheric shape is defined by the following equation.

$$Z = \frac{h^2/r}{1+\sqrt{1-(1+\kappa)(h/r)^2}} + \sum A_n h^n$$

where Z is the distance from a point on an aspheric surface, located at a height h measured from the optical axis, to a tangent plane defined with respect to the vertex of the aspheric surface, h is the height as measured from the optical axis, r is the radius of curvature of the vertex, K is a conic constant, and An is an n^{th} order aspheric surface coefficient.

[0283] FIGS. **1**B, **2**B, **3**B, **4**B, and **5**B are longitudinal aberration diagrams showing what state the imaging optical systems according to the first, second, third, fourth, and fifth embodiments assume.

[0284] In each longitudinal aberration diagram, portion (a) shows the longitudinal aberrations at the wide-angle end, portion (b) shows the longitudinal aberrations at the middle position, and portion (c) shows the longitudinal aberrations at the telephoto end. Each of portions (a), (b) and (c) of these longitudinal aberration diagrams shows spherical aberration (SA (mm)), astigmatism (AST (mm)), and distortion (DIS (%)) in this order from left to right. In each spherical aberration diagram, the ordinate indicates the F number (designated by "F" on the drawings), the solid curve indicates a characteristic in response to a d-line, the shorter dashed curve indicates a characteristic in response to an F-line, and the longer dashed curve indicates a characteristic in response to a C-line. In each astigmatism diagram, the ordinate indicates the image height (designated by "H" on the drawings), the solid curve indicates a characteristic with respect to a sagittal plane (designated by "s" on the drawings), and the dotted curve indicates a characteristic with respect to a meridional plane (designated by "m" on the drawings). Furthermore, in each distortion diagram, the ordinate indicates the image height (designated by "H" on the drawings).

[0285] FIGS. **1**C, **2**C, **3**C, **4**C, and **5**C are lateral aberration diagrams showing what state the imaging optical systems according to the first, second, third, fourth, and fifth embodiments assume at the telephoto end.

[0286] In each lateral aberration diagram, the upper three aberration diagrams represent a basic state where no image blur compensation is performed at the telephoto end. On the other hand, the lower three aberration diagrams represent an image blur compensated state where the group of image stabilizer lenses is moved to a predetermined degree perpendicularly to the optical axis at the telephoto end. In the three lateral aberration diagrams representing the basic state, the upper graph shows lateral aberration at an image point corresponding to 70% of the maximum image height. The middle graph shows the lateral aberration at an axial image point. The lower graph shows lateral aberration at an image point corresponding to −70% of the maximum image height. In the three lateral aberration diagrams representing the image blur compensated state, the upper graph shows lateral aberration at an image point corresponding to 70% of the maximum image height. The middle graph shows lateral aberration at an axial image point. The lower graph shows lateral aberration at an image point corresponding to −70% of the maximum image height. Also, in each lateral aberration diagram, the abscissa indicates the distance from a principal ray on the pupil plane. The solid curve indicates a characteristic in response to a d-line. The shorter dashed curve indicates a characteristic in response to an F-line. The longer dashed curve indicates a characteristic in response to a C-line.

[0287] Note that in the imaging optical systems according to the respective examples of numerical values, the magnitudes of movement of the group of image stabilizer lenses in a direction perpendicular to the optical axis at the telephoto end are as follows:

[0288] First example of numerical values: 0.340 mm

[0289] Second example of numerical values: 0.350 mm

[0290] Third example of numerical values: 0.348 mm

[0291] Fourth example of numerical values: 0.351 mm

[0292] Fifth example of numerical values: 0.349 mm

[0293] At the telephoto end at which the shooting distance is infinite (∞), the magnitude of image eccentricity in a situation where the imaging optical system is tilted to 0.3 degrees is equal to the magnitude of image eccentricity in a situation where the group of image stabilizer lenses makes parallel displacement by a distance represented by any of these numerical values in a direction perpendicular to the optical axis.

[0294] As can be seen from these lateral aberration diagrams, the lateral aberration at the axial image point has a sufficient degree of symmetry. It can also be seen that comparing the lateral aberration at an image point corresponding to +70% of the maximum image height with the lateral aberration at an image point corresponding to −70% of the maximum image height in the basic state, their degrees of curvature are both small and their aberration curves have an approximately equal tilt, and therefore, their eccentricity coma aberration and eccentricity astigmatism are both insignificant. This means that even in the image blur compensated state, sufficiently good imaging performance is achieved. In addition, supposing the imaging optical systems have the same image blur compensation angle, as the focal length of the entire imaging optical system shortens, the magnitude of parallel displacement required for image blur compensation decreases. This allows the image blur compensation to be done to a sufficient degree at any zoom position with respect to an image blur compensation angle of about 0.3 degrees without causing a decline in imaging performance.

First Example of Numerical Values

[0295] Following is a first exemplary set of numerical values for the imaging optical system corresponding to the first embodiment shown in FIG. **1**A. Specifically, as the first example of numerical values for the imaging optical system, surface data is shown in Table 1A, aspheric surface data is shown in Table 1B, and various types of data in the infinity in-focus state are shown in Tables 1C-1F.

TABLE 1A

(Surface data)

Surface No.	r	d	nd	vd	Effective diameter
Object surface	∞				
1	90.10290	1.20000	1.84666	23.8	24.773
2	59.23570	6.93240	1.49700	81.6	23.749
3	−280.94820	0.20000			23.386
4	44.38180	4.64010	1.49700	81.6	20.573
5	141.93270	Variable			20.258
6	96.78490	1.00000	1.95347	32.6	13.231
7	18.86630	5.70110			10.904
8	−38.17850	0.65900	1.59462	66.8	10.436
9	23.41150	3.68120	1.86672	19.8	9.594
10	−69.86610	1.74760			9.358
11	−29.23560	0.60000	1.88300	40.8	8.624
12	542.90170	Variable			8.369
13 (Aperture)	∞	1.40000			7.176
14	18.33090	3.15260	1.52711	57.2	8.087
15	−378.74380	2.24620			8.070
16	18.17170	0.60000	1.95698	32.3	8.050
17	12.06780	4.65620	1.52092	60.8	7.669

TABLE 1A-continued

(Surface data)

Surface No.	r	d	nd	vd	Effective diameter
18	−49.83060	1.96370			7.515
19	−22.70500	0.60000	1.99236	29.7	7.160
20	−843.60570	Variable			7.254
21	17.31530	2.29190	1.49700	81.6	7.832
22	47.62670	2.13040			7.735
23*	71.12630	3.30940	1.58699	59.5	7.622
24*	−28.91280	Variable			7.707
25	216.95880	2.02110	1.94372	18.0	8.379
26	−40.67040	0.60000	1.80334	32.2	8.401
27	27.07710	Variable			8.420
28	−19.87370	1.00000	1.82868	43.1	11.234
29	−58.94070	0.50000			12.663
30	109.76350	2.96010	1.76918	34.3	14.777
31	−144.98430	Variable			
32	∞	2.10000	1.51680	64.2	
33	∞	1.00000			
34	∞	BF			
Image plane	∞				

TABLE 1B

(Aspheric surface data)

23rd surface
K = 2.63837E+00, A4 = −3.75089E−05, A6 = 7.29717E−07, A8 = 8.23449E−10 A10 = 9.78133E−11, A12 = −5.65229E−13
24th surface
K = −4.87684E−01, A4 = 4.48028E−05, A6 = 7.78441E−07, A8 = 3.87499E−10 A10 = 1.12740E−10, A12 = −3.25867E−13

(Various Types of Data in Infinity in-Focus State)

TABLE 1C

(Various types of data)
(Zoom ratio: 6.65091)

	Wide-angle	Middle	Telephoto
Focal length	28.9887	74.7234	192.8010
F number	4.16046	5.80386	7.38074
Angle of view	37.1877	15.4912	6.1980
Image height	21.1600	21.6300	21.6300
Total lens length	112.8021	138.1617	158.9887
BF	0.00000	0.00000	0.00000
d5	0.9677	19.9101	35.5300
d12	17.9193	9.4440	1.7944
d20	4.4987	2.4455	0.8000
d24	1.7038	2.8663	3.5734
d27	15.9632	16.1916	19.4165
d31	12.8500	28.4927	38.9884
Entrance pupil position	28.2608	72.2588	143.0679
Exit pupil position	−45.4074	−59.6027	−70.4186
Anterior principal point	38.7453	53.1738	−192.0587
Posterior principal point	83.8134	63.4383	−33.8123

TABLE 1D

(Data about single lenses)

Lens	Start surface	Focal length
1	1	−207.9336
2	2	99.1038
3	4	127.9079
4	6	−24.7328

TABLE 1D-continued

(Data about single lenses)

Lens	Start surface	Focal length
5	8	−24.3089
6	9	20.6097
7	11	−31.4021
8	14	33.2620
9	16	−39.4375
10	17	19.1431
11	19	−23.5211
12	21	53.4015
13	23	35.4544
14	25	36.4314
15	26	−20.1547
16	28	−36.6072
17	30	81.6285

TABLE 1E

(Data about zoom lens groups)

Group	Start surface	Focal length	Lens configuration length	Anterior principal point	Posterior principal point
1	1	77.21746	12.97250	2.91283	7.28168
2	6	−13.77232	13.38890	3.73110	7.73141
3	13	37.13341	14.61870	−7.62613	−0.25443
4	21	22.84467	7.73170	2.99875	4.56417
5	25	−46.14273	2.62110	1.71174	2.94933
6	28	−69.55417	4.46010	−2.03613	−0.40964

TABLE 1F

(Zoom powers of zoom lens groups)

Group	Start surface	Wide-angle	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	−0.25958	−0.40373	−0.74472
3	13	9.68185	3.59628	2.79645
4	21	−0.07097	−0.24333	−0.36531
5	25	1.63280	1.81060	1.97146
6	28	1.28914	1.51277	1.66474

Second Example of Numerical Values

[0296] Following is a second exemplary set of numerical values for the imaging optical system corresponding to the second embodiment shown in FIG. **2**A. Specifically, as the second example of numerical values for the imaging optical system, surface data is shown in Table 2A, aspheric surface data is shown in Table 2B, and various types of data in the infinity in-focus state are shown in Tables 2C-2F.

TABLE 2A

(Surface data)

Surface No.	r	d	nd	vd	Effective diameter
Object surface	∞				
1	93.38500	1.20000	1.84666	23.8	24.106
2	60.44080	6.47880	1.49700	81.6	22.821
3	−254.35560	0.20000			22.413
4	43.18570	4.24470	1.49700	81.6	18.739

TABLE 2A-continued

(Surface data)

Surface No.	r	d	nd	vd	Effective diameter
5	157.09070	Variable			18.462
6	139.63390	1.00000	1.92003	35.9	13.202
7	18.94060	5.54740			10.831
8	−39.96360	0.65900	1.59341	67.0	10.393
9	23.14480	3.69620	1.86317	20.3	9.586
10	−70.87870	2.32030			9.354
11	−26.99070	0.60000	1.88296	40.8	8.267
12	1528.98670	Variable			8.043
13 (Aperture)	∞	1.40000			7.176
14	19.79540	3.25900	1.52986	55.8	8.146
15	−105.27840	2.23430			8.149
16	18.76860	0.60000	1.96234	31.8	8.061
17	12.45390	4.44460	1.53351	54.0	7.698
18	−58.18580	1.72980			7.545
19	−24.36650	0.60000	1.97700	30.8	7.270
20	135.37870	Variable			7.358
21	19.29630	3.21910	1.49700	81.6	8.131
22	−144.37450	3.25250			8.068
23*	450.22950	1.99400	1.58699	59.5	7.682
24*	−28.52620	Variable			7.719
25	−354.64850	2.09280	1.94798	19.5	8.352
26	−30.10550	0.60000	1.80449	31.4	8.400
27	32.88070	Variable			8.487
28	−22.02600	1.00000	1.79990	44.5	11.542
29	−64.36980	0.67320			12.806
30	252.42800	2.49780	1.84568	22.3	14.371
31	−113.60360	Variable			
32	∞	2.10000	1.51680	64.2	
33	∞	1.00000			
34	∞	BF			
Image plane	∞				

TABLE 2B

(Aspheric surface data)

23rd surface
K = −5.00000E+00, A4 = −6.80359E−05, A6 = 9.24863E−07,
A8 = −5.33973E−09 A10 = 3.23148E−10, A12 = −1.78860E−12
24th surface
K = 1.81265E+00, A4 = 1.89226E−05, A6 = 1.01029E−06,
A8 = −5.28472E−09 A10 = 3.04395E−10, A12 = −1.23164E−12

(Various Types of Data in Infinity in-Focus State)

TABLE 2C

(Various types of data)
(Zoom ratio: 6.65357)

	Wide-angle	Middle	Telephoto
Focal length	28.9794	74.7361	192.8162
F number	4.16053	5.95443	7.38165
Angle of view	36.7545	15.4926	6.1304
Image height	20.4600	21.6300	21.6300
Total lens length	112.7930	137.6008	158.9777
BF	0.00000	0.00000	0.00000
d5	1.1516	17.8465	34.4419
d12	16.8378	8.3951	1.7654
d20	4.2308	2.2115	0.8000
d24	2.2799	4.6044	4.3321
d27	16.7837	14.4138	20.4596
d31	12.8500	31.5471	38.5534
Entrance pupil position	27.4907	64.5952	141.2994
Exit pupil position	−47.5629	−63.4954	−72.2329

TABLE 2C-continued

(Various types of data)
(Zoom ratio: 6.65357)

	Wide-angle	Middle	Telephoto
Anterior principal point	38.8192	51.2798	−180.7116
Posterior principal point	83.8136	62.8646	−33.8385

TABLE 2D

(Data about single lenses)

Lens	Start surface	Focal length
1	1	−205.7934
2	2	98.9385
3	4	118.3732
4	6	−23.9126
5	8	−24.6030
6	9	20.5882
7	11	−30.0329
8	14	31.7333
9	16	−40.3441
10	17	19.6582
11	19	−21.0969
12	21	34.4734
13	23	45.7726
14	25	34.5949
15	26	−19.4527
16	28	−42.3033
17	30	92.9322

TABLE 2E

(Data about zoom lens groups)

Group	Start surface	Focal length	Lens configuration length	Anterior principal point	Posterior principal point
1	1	73.83046	12.12350	3.02330	7.09929
2	6	−13.14402	13.82290	3.89670	8.10468
3	13	41.22271	14.26770	−9.88613	−1.73997
4	21	21.35212	8.46560	3.21513	4.46051
5	25	−44.61667	2.69280	1.30544	2.59593
6	28	−81.62064	4.17100	−2.45525	−1.00244

TABLE 2F

(Zoom powers of zoom lens groups)

Group	Start surface	Wide-angle	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	−0.25969	−0.38751	−0.75873
3	13	3.43654	2.19760	2.01004
4	21	−0.20823	−0.43179	−0.52973
5	25	1.68946	1.86214	2.06594
6	28	1.25023	1.47836	1.56472

Third Example of Numerical Values

[0297] Following is a third exemplary set of numerical values for the imaging optical system corresponding to the third embodiment shown in FIG. **3**A. Specifically, as the third example of numerical values for the imaging optical system, surface data is shown in Table 3A, aspheric surface data is shown in Table 3B, and various types of data in the infinity in-focus state are shown in Tables 3C-3F.

TABLE 3A

(Surface data)					
Surface No.	r	d	nd	vd	Effective diameter
Object surface	∞				
1	89.39310	1.20000	1.84666	23.8	24.744
2	59.08770	7.01900	1.49700	81.6	23.412
3	−261.65280	0.20000			22.887
4	43.01610	4.49310	1.49700	81.6	20.080
5	119.92310	Variable			19.741
6	83.79430	1.00000	1.95302	32.7	13.669
7	18.79360	6.51330			11.226
8	−36.45670	0.65900	1.59342	67.0	10.442
9	23.05660	3.70870	1.86837	20.4	9.583
10	−70.68230	1.78390			9.346
11	−28.97300	0.60000	1.88294	40.8	8.597
12	767.52780	Variable			8.347
13 (Aperture)	∞	1.40000			7.175
14	18.98150	3.15730	1.52706	57.3	8.027
15	−164.90740	1.99820			8.025
16	18.42970	0.60000	1.95402	32.6	8.006
17	12.18010	4.55670	1.52181	60.3	7.631
18	−51.19390	1.70990			7.474
19	−23.77660	0.60000	1.99578	29.5	7.152
20	−689.93870	Variable			7.228
21	20.06570	2.48940	1.49700	81.6	7.869
22	146.51020	2.99990			7.789
23*	292.70690	2.07450	1.58699	59.5	7.540
24*	−27.59030	Variable			7.600
25	290.10420	2.11100	1.95145	18.7	8.370
26	−36.00030	0.60000	1.80342	32.2	8.401
27	28.04480	Variable			8.439
28	−18.84090	1.00000	1.84252	42.4	10.951
29	−57.14670	0.58670			12.440
30	122.40400	3.20170	1.74466	38.7	14.625
31	−99.94240	Variable			
32	∞	2.10000	1.51680	64.2	
33	∞	1.00000			
34	∞	BF			
Image plane	∞				

TABLE 3B

(Aspheric surface data)

23rd surface
K = 5.00000E+00, A4 = −5.96112E−05, A6 = 8.16552E−07, A8 = 8.09756E−10 A10 = 1.98774E−10, A12 = −8.27231E−13
24th surface
K = 1.88093E+00, A4 = 2.67197E−05, A6 = 8.11536E−07, A8 = 2.85280E−09 A10 = 1.42987E−10, A12 = −8.71894E−15

(Various Types of Data in Infinity in-Focus State)

TABLE 3C

(Various types of data) (Zoom ratio: 6.65330)			
	Wide-angle	Middle	Telephoto
Focal length	28.9799	74.7535	192.8118
F number	4.15987	5.71599	7.38089
Angle of view	36.7522	15.4855	6.2115
Image height	20.8800	21.6300	21.6300
Total lens length	112.0885	135.2097	158.9524
BF	0.00000	0.00000	0.00000
d5	0.6000	19.4360	35.6171
d12	17.7695	8.4958	1.7816
d20	4.7515	2.2708	0.8500
d24	1.7084	3.6014	2.8630
d27	15.0738	15.4479	18.2846
d31	12.8500	26.6238	40.2372
Entrance pupil position	28.2888	71.1897	146.8197
Exit pupil position	−44.9962	−57.2933	−71.0917
Anterior principal point	38.5930	48.3602	−183.6243
Posterior principal point	83.1086	60.4561	−33.8594

TABLE 3D

(Data about single lenses)		
Lens	Start surface	Focal length
1	1	−209.6654
2	2	97.6971
3	4	132.3948
4	6	−25.6140
5	8	−23.7034
6	9	20.3957
7	11	−31.6093
8	14	32.4892
9	16	−39.5012
10	17	19.3326
11	19	−24.7408
12	21	46.4771
13	23	43.0576
14	25	33.7670
15	26	−19.5398
16	28	−33.7648
17	30	74.3420

TABLE 3E

(Data about zoom lens groups)					
Group	Start surface	Focal length	Lens configuration length	Anterior principal point	Posterior principal point
1	1	77.61111	12.91210	2.78850	7.14845
2	6	−13.87490	14.26490	4.06986	8.26886
3	13	35.90345	14.02210	−6.13051	0.40724
4	21	23.98849	7.56380	3.14279	4.29647
5	25	−47.39546	2.71100	1.70770	2.99547
6	28	−65.78898	4.78840	−2.41412	−0.76204

TABLE 3F

(Zoom powers of zoom lens groups)				
Group	Start surface	Wide-angle	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	−0.26030	−0.40256	−0.75879
3	13	45.92215	4.44253	3.64379
4	21	−0.01490	−0.20220	−0.27093
5	25	1.59403	1.74678	1.91530
6	28	1.31552	1.52487	1.73156

Fourth Example of Numerical Values

[0298] Following is a fourth exemplary set of numerical values for the imaging optical system corresponding to the fourth embodiment shown in FIG. **4**A. Specifically, as the fourth example of numerical values for the imaging optical system, surface data is shown in Table 4A, aspheric surface data is shown in Table 4B, and various types of data in the infinity in-focus state are shown in Tables 4C-4F.

TABLE 4A

(Surface data)					
Surface No.	r	d	nd	vd	Effective diameter
Object surface	∞				
1	91.07200	1.20000	1.84666	23.8	23.451
2	58.45620	6.32950	1.49700	81.6	22.172
3	−230.31680	0.20000			21.667
4	41.41310	4.23200	1.49700	81.6	18.804
5	119.66320	Variable			18.488
6	93.92320	1.00000	1.95152	32.8	13.251
7	18.22590	6.01180			10.904
8	−40.06930	0.65900	1.59353	67.0	10.357
9	21.45130	3.92760	1.86886	20.9	9.577
10	−65.44920	2.14870			9.350
11	−26.64300	0.60000	1.88300	40.8	8.365
12	2000.00000	Variable			8.142
13 (Aperture)	∞	1.40000			7.175
14	19.66100	3.09460	1.53232	54.6	8.020
15	−150.34770	2.21410			8.027
16	18.41180	0.60000	1.99890	28.9	8.022
17	12.34910	4.45180	1.53512	53.3	7.654
18	−56.62900	1.74820			7.504
19	−24.57010	0.60000	1.97345	30.6	7.211
20	121.62620	Variable			7.294
21	19.22620	2.92120	1.49700	81.6	7.868
22	−335.45030	2.68680			7.817
23*	132.83390	2.88940	1.58699	59.5	7.578
24*	−29.23300	Variable			7.659
25	1125.71610	2.21030	1.94899	18.4	8.364
26	−30.82570	0.60000	1.79893	30.9	8.400

TABLE 4A-continued

(Surface data)					
Surface No.	r	d	nd	vd	Effective diameter
27	30.24630	Variable			8.446
28	−19.92460	1.00000	1.80520	44.2	10.719
29	−56.08430	0.50000			11.942
30	141.20860	3.34570	1.80918	33.9	13.536
31	−65.96530	Variable			13.858
32	−77.85290	0.90000	1.99402	29.6	15.706
33	−271.88690	Variable			16.116
34	∞	2.10000	1.51680	64.2	
35	∞	1.00000			
36	∞	BF			
Image plane	∞				

TABLE 4B

(Aspheric surface data)
23rd surface
K = 0.00000E+00, A4 = −3.45181E−05, A6 = 7.54614E−07, A8 = 1.49928E−09 A10 = 9.30690E−11, A12 = −5.69505E−13
24th surface
K = 0.00000E+00, A4 = 4.14702E−05, A6 = 8.08831E−07, A8 = 1.34409E−09 A10 = 1.01596E−10, A12 = −3.07347E−13

(Various Types of Data in Infinity in-Focus State)

TABLE 4C

(Various types of data) (Zoom ratio: 6.66602)			
	Wide-angle	Middle	Telephoto
Focal length	28.9279	74.7073	192.8342
F number	4.16045	5.74141	7.38120
Angle of view	36.7900	15.4990	6.1612
Image height	20.6900	21.6300	21.6300
Total lens length	112.8085	136.0732	158.9817
BF	0.00000	0.00000	0.00000
d5	0.6000	18.2707	34.7853
d12	17.1989	7.7230	1.7618
d20	4.0249	1.9070	0.8500
d24	2.2953	3.9935	2.6926
d27	14.4230	13.1757	17.7055
d31	0.8329	16.5345	12.9388
d33	12.8500	13.8927	27.6909
Entrance pupil position	26.9806	65.8742	143.5504
Exit pupil position	−44.7949	−51.8512	−64.6710
Anterior principal point	37.2326	32.9545	−238.7267
Posterior principal point	83.8806	61.3660	−33.8525

TABLE 4D

(Data about single lenses)		
Lens	Start surface	Focal length
1	1	−196.0942
2	2	94.4969
3	4	125.1788
4	6	−23.9205
5	8	−23.4464
6	9	18.9937
7	11	−29.7725
8	14	32.8710
9	16	−39.4978
10	17	19.3818
11	19	−20.9560
12	21	36.6880
13	23	41.0898
14	25	31.6463
15	26	−19.0259
16	28	−38.8589
17	30	55.9689
18	32	−110.0009

TABLE 4E

(Data about zoom lens groups)					
Group	Start surface	Focal length	Lens configuration length	Anterior principal point	Posterior principal point
1	1	74.91797	11.96150	2.67440	6.72042
2	6	−13.60299	14.34710	3.93403	8.33209
3	13	43.68476	14.10870	−10.77441	−2.46916
4	21	21.01395	8.49740	3.19484	4.70746
5	25	−48.46814	2.81030	1.60895	2.94889
6	28	−150.29826	4.84570	−7.39730	−5.95670
7	32	−110.00093	0.90000	−0.18152	0.26609

TABLE 4F

(Zoom powers of zoom lens groups)				
Group	Start surface	Wide-angle	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	−0.26393	−0.40163	−0.78383
3	13	3.10879	2.01733	1.94873
4	21	−0.22142	−0.46586	−0.51186
5	25	1.58936	1.79134	1.95519
6	28	1.16854	1.27823	1.31643
7	32	1.14437	1.15379	1.27905

Fifth Example of Numerical Values

[0299] Following is a fifth exemplary set of numerical values for the imaging optical system corresponding to the fifth embodiment shown in FIG. **5**A. Specifically, as the fifth example of numerical values for the imaging optical system, surface data is shown in Table 5A, aspheric surface data is shown in Table 5B, and various types of data in the infinity in-focus state are shown in Tables 5C-5F.

TABLE 5A

(Surface data)					
Surface No.	r	d	nd	vd	Effective diameter
Object surface	∞				
1	90.03880	1.20000	1.84666	23.8	24.419
2	59.49890	6.88130	1.49700	81.6	23.425
3	−238.02650	0.20000			23.075
4	43.24200	4.46730	1.49700	81.6	20.164
5	120.72190	Variable			19.833
6	100.31340	1.00000	1.95339	32.6	13.120
7	18.70010	5.60350			10.817
8	−38.17100	0.65900	1.59300	67.1	10.401
9	22.99430	3.76860	1.86737	20.3	9.581
10	−64.91860	1.67570			9.349
11	−28.55750	0.60000	1.88300	40.8	8.653
12	841.96650	Variable			8.403
13 (Aperture)	∞	1.40000			7.175
14	18.86310	3.15490	1.53310	54.2	8.042
15	−186.74870	2.34810			8.037
16	18.16240	0.60000	1.96749	31.4	7.995
17	12.16800	4.48690	1.52660	57.5	7.620

TABLE 5A-continued

(Surface data)					
Surface No.	r	d	nd	vd	Effective diameter
18	−56.78280	2.02070			7.457
19	−23.01020	0.60000	1.99774	29.3	7.087
20	257.24460	Variable			7.179
21	17.91410	2.39390	1.49700	81.6	7.845
22	60.47700	1.50600			7.772
23	−151.02030	0.95170	1.61512	62.7	7.742
24	−67.22120	0.20200			7.740
25*	129.48610	2.68730	1.60699	56.2	7.666
26*	−28.96240	Variable			7.723
27	313.39890	2.16870	1.94590	18.0	8.367
28	−34.02540	0.60000	1.81627	29.3	8.392
29	28.61340	Variable			8.418
30	−19.75750	1.00000	1.81708	43.6	11.261
31	−57.66910	0.57080			12.677
32	110.58120	2.89310	1.77513	28.6	14.789
33	−155.85260	Variable			
34	∞	2.10000	1.51680	64.2	
35	∞	1.00000			
36	∞	BF			
Image plane	∞				

TABLE 5B

(Aspheric surface data)
25th surface
K = −5.38904E+01, A4 = −3.89899E−05, A6 = 6.61044E−07, A8 = 2.96723E−09 A10 = 1.15167E−10, A12 = −6.86274E−13
26th surface
K = 1.41076E+00, A4 = 4.20336E−05, A6 = 7.19136E−07, A8 = 3.35160E−09 A10 = 1.06972E−10, A12 = −2.50402E−13

(Various Types of Data in Infinity in-Focus State)

TABLE 5C

(Various types of data) (Zoom ratio: 6.65181)			
	Wide-angle	Middle	Telephoto
Focal length	28.9871	74.7438	192.8169
F number	4.15985	5.80061	7.38267
Angle of view	36.7360	15.4905	6.1953
Image height	20.6500	21.6300	21.6300
Total lens length	112.7959	138.0649	158.9983
BF	0.00000	0.00000	0.00000
d5	0.6945	19.6632	35.3906
d12	17.9169	9.3631	1.7786
d20	4.1749	2.3141	0.8000
d26	1.9042	3.1688	3.6242

TABLE 5C-continued

(Various types of data) (Zoom ratio: 6.65181)			
	Wide-angle	Middle	Telephoto
d29	16.5159	16.5350	20.0114
d33	12.8500	28.3448	38.6515
Entrance pupil position	27.5063	71.0651	142.0332
Exit pupil position	−45.9294	−59.8930	−70.5711
Anterior principal point	38.1990	52.4328	−191.9524
Posterior principal point	83.8087	63.3211	−33.8186

TABLE 5D

(Data about single lenses)		
Lens	Start surface	Focal length
1	1	−210.9867
2	2	96.5170
3	4	133.0191

TABLE 5D-continued

(Data about single lenses)		
Lens	Start surface	Focal length
4	6	−24.2535
5	8	−24.1021
6	9	19.9742
7	11	−31.2704
8	14	32.3098
9	16	−40.0794
10	17	19.4660
11	19	−21.1463
12	21	50.2766
13	23	196.0953
14	25	39.2449
15	27	32.5473
16	28	−18.9597
17	30	−37.2237
18	32	83.8487

TABLE 5E

(Data about zoom lens groups)					
Group	Start surface	Focal length	Lens configuration length	Anterior principal point	Posterior principal point
1	1	76.84915	12.74860	2.76980	7.07585
2	6	−13.92215	13.30680	3.58400	7.58494
3	13	40.29684	14.61060	−10.29737	−1.79000
4	21	21.33848	7.74090	3.05457	4.81994
5	27	46.39917	2.76870	1.71360	3.02924
6	30	−70.09527	4.46390	−2.04382	−0.44404

TABLE 5F

(Zoom powers of zoom lens groups)				
Group	Start surface	Wide-angle	Middle	Telephoto
1	1	0.00000	0.00000	0.00000
2	6	−0.26280	−0.40939	−0.76162
3	13	4.29855	2.53639	2.17021
4	21	−0.15781	−0.34228	−0.46315
5	27	1.64350	1.81528	1.97978
6	30	1.28736	1.50750	1.65549

(Values Corresponding to Inequalities)

[0300] Values, corresponding to the inequalities (1) to (15), of the respective examples of numerical values are shown in the following Table 6:

TABLE 6

	Inequality	1st example of numerical values	2nd example of numerical values	3rd example of numerical values	4th example of numerical values	5th example of numerical values
(1)	Th_IS_Obj/Th_G3	0.170	0.174	0.158	0.174	0.178
(2)	Th_G4_Air/Th_G4	0.276	0.384	0.397	0.316	0.195
(3)	Th_IS_Img/Th_G3	0.149	0.134	0.135	0.138	0.153
(4)	(R2_LG3F1 + R1_LG3F2)/ (R2_LG3F1 − R1_LG3F2)	0.908	0.697	0.799	0.782	0.823
(5)	(R2_LG4F1 + R1_LG4F2)/ (R2_LG4F1 − R1_LG4F2)	−5.053	−0.514	−3.004	0.433	−0.428
(6)	nd_LG4Fp1	1.497	1.497	1.497	1.497	1.497
(7)	ThwG5_G6/fw	0.551	0.579	0.520	0.499	0.570
(8)	fG1/fT	0.401	0.383	0.403	0.389	0.399
(9)	fG5/fw	−1.592	−1.540	−1.635	−1.675	−1.601
(10)	Th_G2_G3/Yw	0.913	0.891	0.918	0.899	0.935
(11)	BFw/Yw	0.754	0.780	0.764	0.771	0.772
(12)	TTLw/Yw	5.331	5.512	5.370	5.452	5.462
(13)	(TTLt − TTLw)/TTLt	0.291	0.291	0.295	0.291	0.291
(14)	Th_IS_Obj/Yw	0.106	0.109	0.096	0.107	0.114
(15)	Th_IS_Img/Yw	0.093	0.085	0.082	0.084	0.098

[0301] While the foregoing has described what are considered to be the best mode and/or other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the present teachings.

INDUSTRIAL APPLICABILITY

[0302] The imaging optical system according to the present disclosure is applicable to various types of cameras including digital still cameras, digital cameras, of which the lens is interchangeable, digital camcorders, cameras for cellphones and smartphones, and cameras for personal digital assistants (PDAs), surveillance cameras for surveillance systems, Web cameras, and onboard cameras. Among other things, the present disclosure is particularly suitably applicable to imaging optical systems that are required to provide high image quality such as digital still camera systems and digital camcorder systems.

1. An imaging optical system comprising:

a first lens group having positive power;

a second lens group having negative power;

a third lens group having positive power;

a fourth lens group having positive power;

a fifth lens group having negative power; and

a sixth lens group having power,

the first, second, third, fourth, fifth, and sixth lens groups being arranged in this order such that the first lens group is located closer to an object than any of the second, third, fourth, fifth or sixth lens group is, and that the sixth lens group is located closer to an image plane than any of the first, second, third, fourth, or fifth lens group is,

an interval between each pair of lens groups that are adjacent to each other changing as at least the first, second, third, fourth, fifth, and sixth lens groups move in an optical axis direction aligned with an optical axis of the imaging optical system while the imaging optical system is zooming.

2. The imaging optical system of claim **1**, wherein

the third lens group includes:

a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization; and

a group of fixed lenses G**3**Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization, and

the imaging optical system satisfies the following inequality (1):

$$0.06 < Th\_IS\_Obj/Th\_G3 < 0.50 \quad (1)$$

where Th_IS_Obj is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G**3**Obj, and

Th_G**3** is a thickness of the third lens group on the optical axis.

3. The imaging optical system of claim **1**, wherein

the fourth lens group includes at least two lenses,

the imaging optical system satisfies the following inequality (2):

$$0.05 < Th\_G4\_Air/Th\_G4 < 0.80 \quad (2)$$

where Th_G**4** Air is a maximum value of an air gap on the optical axis between adjacent lenses included in at least two lenses that form the fourth lens group; and

Th_G**4** is a thickness of the fourth lens group on the optical axis.

4. The imaging optical system of claim 1, wherein the third lens group includes:

a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization;

a group of fixed lenses G3Obj located closer to the object than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization; and

a group of fixed lenses G3Img located closer to the image plane than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization.

5. The imaging optical system of claim 1, wherein an object-side surface of lens LG3R1 located closer to the image plane than any of other negative lenses that form part of the third lens group has a convex surface facing the image plane.

6. The imaging optical system of claim 1, wherein the third lens group includes:

a group of image stabilizer lenses consisting of a plurality of lenses configured to move perpendicularly to the optical axis during an image stabilization; and

a group of fixed lenses G3Img located closer to the image plane than the group of image stabilizer lenses is, consisting of one or more lenses, and configured not to move perpendicularly to the optical axis during the image stabilization;

the imaging optical system satisfies the following inequality (3):

$$0.05 < \mathrm{Th\_IS\_Img} / \mathrm{Th\_G3} < 0.80 \tag{3}$$

where Th_IS_Img is an air gap on the optical axis between the group of image stabilizer lenses and the group of fixed lenses G3Img, and

Th_G3 is a thickness of the third lens group on the optical axis.

7. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (4):

$$0.0 < (\mathrm{R2\_LG3F1} + \mathrm{R1\_LG3F2}) / (\mathrm{R2\_LG3F1} - \mathrm{R1\_LG3F2}) < 1.0 \tag{4}$$

where R2_LG3F1 is a radius of curvature of an image-side surface of a lens LG3F1 located closer to the object than any other lens belonging to the third lens group, and

R1_LG3F2 is a radius of curvature of an object-side surface of a lens LG3F2 located adjacent to the lens LG3F1 and closer to the image plane than the lens LG3F1 is.

8. The imaging optical system of claim 1, wherein an image-side surface of a positive lens LG4Fp1 located closer to the object than any other lens belonging to the fourth lens group has a convex surface facing the object.

9. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (5):

$$-10.0 < (\mathrm{R2\_LG4F1} + \mathrm{R1\_LG4F2}) / (\mathrm{R2\_LG4F1} - \mathrm{R1\_LG4F2}) < 1.0 \tag{5}$$

where R2_LG4F1 is a radius of curvature of an image-side surface of a lens LG4F1 located closer to the object than any other lens belonging to the fourth lens group, and

R1_LG4F2 is a radius of curvature of an object-side surface of a lens LG4F2 located adjacent to the lens LG4F1 and closer to the image plane than the lens LG4F1 is.

10. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (6):

$$\mathrm{nd\_LG4Fp1} < 1.6 \tag{6}$$

where nd_LG4Fp1 is a refractive index of a positive lens LG4Fp1 located closer to the object than any other lens belonging to the fourth lens group is.

11. The imaging optical system of claim 1, wherein the fifth lens group is configured to move toward the image plane while the imaging optical system is focusing from an infinity in-focus object toward a close-object in-focus state.

12. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (7):

$$0.1 < \mathrm{ThwG5\_G6} / fw < 0.8 \tag{7}$$

where ThwG5_G6 is an interval measured on the optical axis between the fifth lens group and the sixth lens group in the imaging optical system at a wide-angle end; and

fw is a focal length of the imaging optical system at the wide-angle end.

13. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (8):

$$0.2 < fG1 / fT < 1.0 \tag{8}$$

where fG1 is a focal length of the first lens group, and

fT is a focal length of the imaging optical system at a telephoto end.

14. The imaging optical system of claim 1, wherein the imaging optical system satisfies the following inequality (9):

$$-2.5 < fG5 / fw < -1.0 \tag{9}$$

where fG5 is a focal length of the fifth lens group, and

fw is a focal length of the imaging optical system at a wide-angle end.

15. The imaging optical system of claim **1**, wherein the imaging optical system satisfies the following inequality (10):

$$0.5 < \text{Th\_G2\_G3} / Yw < 3.0 \tag{10}$$

where Th_**G2**_**G3** is an air gap measured on the optical axis between the second lens group and the third lens group in the imaging optical system at a wide-angle end, and

Yw is a maximum image height of the imaging optical system at the wide-angle end.

16. The imaging optical system of claim **1**, wherein the imaging optical system satisfies the following inequality (11):

$$0.3 < BFw / Yw < 3.0 \tag{11}$$

where BFw is a back focus of the imaging optical system at a wide-angle end; and

Yw is a maximum image height of the imaging optical system at the wide-angle end.

17. The imaging optical system of claim **1**, wherein the imaging optical system satisfies the following inequality (12):

$$2.0 < TTLw / Yw < 10.0 \tag{12}$$

where TTLw is a total optical length of the imaging optical system at a wide-angle end; and

Yw is a maximum image height of the imaging optical system at the wide-angle end.

18. The imaging optical system of claim **1**, wherein the imaging optical system satisfies the following inequality (13):

$$0.1 < (TTLt - TTLw) / TTLt < 0.5 \tag{13}$$

where TTLt is a total optical length of the imaging optical system at a telephoto end; and

TTLw is a total optical length of the imaging optical system at a wide-angle end.

19. A camera system comprising:

an interchangeable lens unit including the imaging optical system of claim **1**; and

a camera body including: an image sensor configured to receive an optical image of an object formed by the imaging optical system and transform the optical image into an electrical image signal; and a camera mount, the camera body being configured to be connected removably to the interchangeable lens unit via the camera mount,

the interchangeable lens unit being configured to form the optical image of the object on the image sensor.

20. An image capture device configured to transform an optical image of an object into an electrical image signal and display and/or store the electrical image signal thus transformed, the image capture device comprising:

the imaging optical system of claim **1** configured to form the optical image of the object; and

an image sensor configured to transform the optical image formed by the imaging optical system into the electrical image signal.

* * * * *