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VARIABLE MAGNIFICATION OPTICAL SYSTEM, OPTICAL DEVICE, AND METHOD FOR MANUFACTURING VARIABLE MAGNIFICATION OPTICAL SYSTEM

Abstract

A variable magnification optical system including, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups is configured so that at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied, and that the following conditional expression is satisfied:

$0.24<(TL/f1)/(ft/fw)<0.55$

where TL is the distance from a lens surface closest to the object side to the image plane, f1 is the focal length of the first lens group, ft is the focal length of the variable magnification optical system in a telephoto end state, and fw is the focal length of the variable magnification optical system in a wide-angle end state.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of International Patent Application No. PCT/JP2023/038491 filed Oct. 25, 2023, which claims priority from Japanese Patent Application No. 2022-177062 filed Nov. 4, 2022, which are incorporated herein by reference.

FIELD
[0002] The present disclosure relates to a variable magnification optical system, an optical device, and a method for manufacturing a variable magnification optical system.
BACKGROUND
[0003] Variable magnification optical systems used in optical devices, such as cameras for photographs, electronic still cameras, and video cameras, have been proposed (see, e.g., Japanese Unexamined Patent Publication No. 2021-189401).
SUMMARY
[0004] A variable magnification optical system of the present disclosure includes, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups: at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied: the variable magnification optical system satisfies the following conditional expression.
[00001] $0.24 < (TL / f1) / (ft / fw) < 0.55$
where [0005] TL: the distance from a lens surface closest to the object side to the image plane [0006] f1: the focal length of the first lens group [0007] ft: the focal length of the variable magnification optical system in a telephoto end state [0008] fw: the focal length of the variable magnification optical system in a wide-angle end state
[0009] A method for manufacturing a variable magnification optical system of the present disclosure includes configuring a variable magnification optical system including, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups so that at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied, and that the following conditional expression is satisfied.

$$0.24<(TL/f1)/(ft/fw)<0.55$$

where [0010] TL: the distance from a lens surface closest to the object side to the image plane [0011] f1: the focal length of the first lens group [0012] ft: the focal length of the variable magnification optical system in a telephoto end state [0013] fw: the focal length of the variable magnification optical system in a wide-angle end state

Description

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. **1** is a cross-sectional view of a variable magnification optical system of a first example focusing on an object at infinity in the wide-angle end state.

[0015] FIG. **2**A shows aberrations of the variable magnification optical system of the first example focusing on an object at infinity in the wide-angle end state, and FIG. **2**B shows aberrations of the variable magnification optical system of the first example focusing on an object at infinity in the telephoto end state.

[0016] FIG. **3** is a cross-sectional view of a variable magnification optical system of a second example focusing on an object at infinity in the wide-angle end state.

[0017] FIG. **4**A shows aberrations of the variable magnification optical system of the second example focusing on an object at infinity in the wide-angle end state, and FIG. **4**B shows aberrations of the variable magnification optical system of the second example focusing on an object at infinity in the telephoto end state.

[0018] FIG. **5** is a cross-sectional view of a variable magnification optical system of a third example focusing on an object at infinity in the wide-angle end state.

[0019] FIG. **6**A shows aberrations of the variable magnification optical system of the third example focusing on an object at infinity in the wide-angle end state, and FIG. **6**B shows aberrations of the variable magnification optical system of the third example focusing on an object at infinity in the telephoto end state.

[0020] FIG. **7** is a cross-sectional view of a variable magnification optical system of a fourth example focusing on an object at infinity in the wide-angle end state.

[0021] FIG. **8**A shows aberrations of the variable magnification optical system of the fourth example focusing on an object at infinity in the wide-angle end state, and FIG. **8**B shows aberrations of the variable magnification optical system of the fourth example focusing on an object at infinity in the telephoto end state.

[0022] FIG. **9** is a cross-sectional view of a variable magnification optical system of a fifth example focusing on an object at infinity in the wide-angle end state.

[0023] FIG. **10**A shows aberrations of the variable magnification optical system of the fifth example focusing on an object at infinity in the wide-angle end state, and FIG. **10**B shows aberrations of the variable magnification optical system of the fifth example focusing on an object at infinity in the telephoto end state.

[0024] FIG. **11** is a cross-sectional view of a variable magnification optical system of a sixth example focusing on an object at infinity in the wide-angle end state.

[0025] FIG. **12**A shows aberrations of the variable magnification optical system of the sixth example focusing on an object at infinity in the wide-angle end state, and FIG. **12**B shows aberrations of the variable magnification optical system of the sixth example focusing on an object at infinity in the telephoto end state.

[0026] FIG. **13** schematically shows a camera including a variable magnification optical system of the embodiment.

[0027] FIG. **14** is a flowchart outlining a method for manufacturing a variable magnification optical system of the embodiment.

DESCRIPTION OF EMBODIMENTS

[0028] The following describes a variable magnification optical system, an optical device, and a method for manufacturing a variable magnification optical system of an embodiment of the present application.

[0029] A variable magnification optical system of the present embodiment includes, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups: at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied: the variable magnification optical system satisfies the following conditional expression.

[00002] $0.24 < (TL / f1) / (ft / fw) < 0.55$ (1)

where [0030] TL: the distance from a lens surface closest to the object side to the image plane [0031] f1: the focal length of the first lens group [0032] ft: the focal length of the variable magnification optical system in a telephoto end state [0033] fw: the focal length of the variable magnification optical system in a wide-angle end state

[0034] The variable magnification optical system of the present embodiment can reduce variations in aberrations, including spherical aberration at varying magnification, by including a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups.

[0035] Conditional expression (1) restricts the ratio between the ratio of the distance from a lens surface closest to the object side to the image plane to the focal length of the first lens group and the ratio of the focal length of the variable magnification optical system in a telephoto end state to that of the variable magnification optical system in a wide-angle end state (variable power ratio). The variable magnification optical system of the present embodiment satisfying conditional expression (1) can reduce variations in aberrations, including spherical aberration at varying magnification.

[0036] If the value of conditional expression (1) exceeds the upper limit in the variable magnification optical system of the present embodiment, the first lens group will have too strong refractive power with respect to the distance from a lens surface closest to the object side to the image plane and the variable power ratio, making it difficult to reduce variations in aberrations, including spherical aberration at varying magnification.

[0037] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (1) to 0.55. To further ensure the effect of the present embodiment, the upper limit of conditional expression (1) is preferably set to 0.53, more preferably to 0.50.

[0038] If the value of conditional expression (1) is below the lower limit in the variable magnification optical system of the present embodiment, the first lens group will have too weak refractive power with respect to the distance from a lens surface closest to the object side to the image plane and the variable power ratio, making it difficult to reduce variations in aberrations, including spherical aberration at varying magnification.

[0039] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (1) to 0.24. To further ensure the effect of the present embodiment, the lower limit of conditional expression (1) is preferably set to 0.28, 0.30, or 0.33, more preferably to 0.36.

[0040] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.

[00003] $3.00 < f1 / (-f2) < 5.80$ (2)

where [0041] f2: the focal length of the second lens group

[0042] Conditional expression (2) restricts the ratio between the focal lengths of the first and second lens groups. The variable magnification optical system of the present embodiment satisfying conditional expression (2) can reduce variations in aberrations, including coma aberration at varying magnification.

[0043] If the value of conditional expression (2) exceeds the upper limit in the variable

magnification optical system of the present embodiment, the second lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0044] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (2) to 5.80. To further ensure the effect of the present embodiment, the upper limit of conditional expression (2) is preferably set to 5.60, more preferably to 5.40.
[0045] If the value of conditional expression (2) is below the lower limit in the variable magnification optical system of the present embodiment, the first lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0046] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (2) to 3.00. To further ensure the effect of the present embodiment, the lower limit of conditional expression (2) is preferably set to 3.30, 3.50, or 3.75, more preferably to 3.90.
[0047] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.
[00004] $0.45 < f1/f3 < 6.00 \quad (3)$
where [0048] f3: the focal length of the third lens group
[0049] Conditional expression (3) restricts the ratio between the focal lengths of the first and third lens groups. The variable magnification optical system of the present embodiment satisfying conditional expression (3) can reduce variations in aberrations, including coma aberration at varying magnification.
[0050] If the value of conditional expression (3) exceeds the upper limit in the variable magnification optical system of the present embodiment, the third lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0051] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (3) to 6.00. To further ensure the effect of the present embodiment, the upper limit of conditional expression (3) is preferably set to 5.50, 5.00, 4.80, or 4.50, more preferably to 4.00.
[0052] If the value of conditional expression (3) is below the lower limit in the variable magnification optical system of the present embodiment, the first lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0053] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (3) to 0.45. To further ensure the effect of the present embodiment, the lower limit of conditional expression (3) is preferably set to 0.50 or 0.55, more preferably to 0.60.
[0054] In the variable magnification optical system of the present embodiment, the subsequent lens group preferably includes a focusing lens group having negative refractive power and moving at focusing, and the following conditional expression is preferably satisfied.
[00005] $0.30 < f2/\mathrm{fF} < 1. \quad (4)$
where [0055] f2: the focal length of the second lens group [0056] fF: the focal length of the focusing lens group
[0057] The variable magnification optical system of the present embodiment can reduce variations in aberrations, including spherical aberration at focusing, by the subsequent lens group including a focusing lens group.
[0058] Conditional expression (4) restricts the ratio between the focal lengths of the second lens

group and the focusing lens group. The variable magnification optical system of the present embodiment satisfying conditional expression (4) can reduce variations in aberrations, including coma aberration at varying magnification and spherical aberration at focusing.
[0059] If the value of conditional expression (4) exceeds the upper limit in the variable magnification optical system of the present embodiment, the focusing lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including spherical aberration at focusing.
[0060] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (4) to 1.00. To further ensure the effect of the present embodiment, the upper limit of conditional expression (4) is preferably set to 0.90, 0.80, or 0.75, more preferably to 0.70.
[0061] If the value of conditional expression (4) is below the lower limit in the variable magnification optical system of the present embodiment, the second lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0062] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (4) to 0.30. To further ensure the effect of the present embodiment, the lower limit of conditional expression (4) is preferably set to 0.33, more preferably to 0.35.
[0063] In the variable magnification optical system of the present embodiment, a final lens group disposed closest to the image plane in the subsequent lens group is preferably fixed with respect to the image plane at varying magnification.
[0064] Such a configuration simplifies a mechanism for moving the lens groups at varying magnification, enabling the variable magnification optical system of the present embodiment to be reduced in size and weight.
[0065] In the variable magnification optical system of the present embodiment, the subsequent lens group preferably includes a focusing lens group having negative refractive power and moving at focusing and a final lens group disposed closest to the image plane, and the following conditional expression is preferably satisfied.
[00006] $2.00 < .\text{Math. } fR \text{ .Math. } / (-fF) < 100.00 \quad (5)$
where [0066] fR: the focal length of the final lens group [0067] fF: the focal length of the focusing lens group
[0068] Conditional expression (5) restricts the ratio between the focal lengths of the final lens group and the focusing lens group. The variable magnification optical system of the present embodiment satisfying conditional expression (5) can reduce variations in aberrations, including coma aberration at varying magnification and spherical aberration at focusing.
[0069] If the value of conditional expression (5) exceeds the upper limit in the variable magnification optical system of the present embodiment, the focusing lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including spherical aberration at focusing.
[0070] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (5) to 100.00. To further ensure the effect of the present embodiment, the upper limit of conditional expression (5) is preferably set to 80.00, 65.00, 55.00, 40.00, or 25.00, more preferably to 15.00.
[0071] If the value of conditional expression (5) is below the lower limit in the variable magnification optical system of the present embodiment, the final lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0072] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (5) to 2.00.

To further ensure the effect of the present embodiment, the lower limit of conditional expression (5) is preferably set to 2.30 or 2.50, more preferably to 2.70.
[0073] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.
[00007] $1.5 < BFw / fw < 0.95$ (6)
where [0074] BFw: the back focal length of the variable magnification optical system focusing on infinity in the wide-angle end state
[0075] Conditional expression (6) restricts the ratio between the focal length of the variable magnification optical system in a wide-angle end state and the back focal length of the variable magnification optical system focusing on infinity in the wide-angle end state. The variable magnification optical system of the present embodiment satisfying conditional expression (6) can correct aberrations, including coma aberration at focusing on infinity in the wide-angle end state, favorably.
[0076] If the value of conditional expression (6) exceeds the upper limit in the variable magnification optical system of the present embodiment, the back focal length will be large with respect to the focal length in the wide-angle end state, making it difficult to correct aberrations, including coma aberration at focusing on infinity in the wide-angle end state, favorably.
[0077] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (6) to 0.95. To further ensure the effect of the present embodiment, the upper limit of conditional expression (6) is preferably set to 0.92, more preferably to 0.90.
[0078] If the value of conditional expression (6) is below the lower limit in the variable magnification optical system of the present embodiment, the back focal length will be small with respect to the focal length in the wide-angle end state, making it difficult to correct aberrations, including coma aberration at focusing on infinity in the wide-angle end state, favorably.
[0079] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (6) to 0.15. To further ensure the effect of the present embodiment, the lower limit of conditional expression (6) is preferably set to 0.20, 0.30, or 0.40, more preferably to 0.45.
[0080] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.
[00008] $0.08 < BFt / ft < 0.24$ (7)
where [0081] BFt: the back focal length of the variable magnification optical system focusing on infinity in the telephoto end state
[0082] Conditional expression (7) restricts the ratio between the focal length of the variable magnification optical system in a telephoto end state and the back focal length of the variable magnification optical system focusing on infinity in the telephoto end state. The variable magnification optical system of the present embodiment satisfying conditional expression (7) can correct aberrations, including coma aberration at focusing on infinity in the telephoto end state, favorably.
[0083] If the value of conditional expression (7) exceeds the upper limit in the variable magnification optical system of the present embodiment, the back focal length will be large with respect to the focal length in the telephoto end state, making it difficult to correct aberrations, including coma aberration at focusing on infinity in the telephoto end state, favorably.
[0084] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (7) to 0.24. To further ensure the effect of the present embodiment, the upper limit of conditional expression (7) is preferably set to 0.22, more preferably to 0.20.
[0085] If the value of conditional expression (7) is below the lower limit in the variable

magnification optical system of the present embodiment, the back focal length will be small with respect to the focal length in the telephoto end state, making it difficult to correct aberrations, including coma aberration at focusing on infinity in the telephoto end state, favorably.
[0086] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (7) to 0.08. To further ensure the effect of the present embodiment, the lower limit of conditional expression (7) is preferably set to 0.09, more preferably to 0.10.
[0087] In the variable magnification optical system of the present embodiment, the plurality of lens groups in the subsequent lens group preferably includes at least one lens group having positive refractive power, and the following conditional expression is preferably satisfied.
[00009] $0.7 < f1 / fRP < 3.4 \quad (8)$
where [0088] fRP: the focal length of a lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power
[0089] The variable magnification optical system of the present embodiment can reduce variations in aberrations, including coma aberration at varying magnification by the subsequent lens group including at least one lens group having positive refractive power.
[0090] Conditional expression (8) restricts the ratio between the focal lengths of the first lens group and a lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power. The variable magnification optical system of the present embodiment satisfying conditional expression (8) can reduce variations in aberrations, including coma aberration at varying magnification.
[0091] If the value of conditional expression (8) exceeds the upper limit in the variable magnification optical system of the present embodiment, the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0092] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (8) to 3.40. To further ensure the effect of the present embodiment, the upper limit of conditional expression (8) is preferably set to 3.30, 3.20, or 3.08, more preferably to 3.00.
[0093] If the value of conditional expression (8) is below the lower limit in the variable magnification optical system of the present embodiment, the first lens group will have too strong refractive power, making it difficult to reduce variations in aberrations, including coma aberration at varying magnification.
[0094] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (8) to 0.70. To further ensure the effect of the present embodiment, the lower limit of conditional expression (8) is preferably set to 0.72, 0.80, 0.85, or 0.90, more preferably to 0.95.
[0095] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.
[00010] $0.5 < Gw / Gt < 1.5 \quad (9)$
where [0096] Gw: the distance from the lens surface closest to the object side in the variable magnification optical system in the wide-angle end state to the centroid position of the variable magnification optical system [0097] Gt: the distance from the lens surface closest to the object side in the variable magnification optical system in the telephoto end state to the centroid position of the variable magnification optical system
[0098] Conditional expression (9) restricts the ratio of the distance from the lens surface closest to the object side in the variable magnification optical system in the wide-angle end state to the centroid position of the variable magnification optical system to the distance from the lens surface

closest to the object side in the variable magnification optical system in the telephoto end state to the centroid position of the variable magnification optical system. In the variable magnification optical system of the present embodiment satisfying conditional expression (9), the change in the centroid position at varying magnification will be small, which enhances usability.
[0099] When the variable magnification optical system of the present embodiment does not satisfy conditional expression (9), the change in the centroid position at varying magnification will be large, which impairs usability.
[0100] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (9) to 1.50. To further ensure the effect of the present embodiment, the upper limit of conditional expression (9) is preferably set to 1.40, 1.30, 1.20, or 1.10, more preferably to 1.00.
[0101] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (9) to 0.50. To further ensure the effect of the present embodiment, the lower limit of conditional expression (9) is preferably set to 0.60, 0.70, or 0.80, more preferably to 0.90.
[0102] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.

$30.00° < \omega w$ (10)

where [0103] ωw: the semi-field angle of the variable magnification optical system in the wide-angle end state
[0104] Conditional expression (10) restricts the semi-field angle of the variable magnification optical system in the wide-angle end state. The variable magnification optical system of the present embodiment satisfying conditional expression (10) can form an image of a wide-spread subject on the image plane.
[0105] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the lower limit of conditional expression (10) to 30.00°. To further ensure the effect of the present embodiment, the lower limit of conditional expression (10) is preferably set to 34.00°, more preferably to 36.00°.
[0106] The variable magnification optical system of the present embodiment preferably satisfies the following conditional expression.

$\omega t < 15.00°$ (11)

where [0107] ωt: the semi-field angle of the variable magnification optical system in the telephoto end state
[0108] Conditional expression (11) restricts the semi-field angle of the variable magnification optical system in the telephoto end state. The variable magnification optical system of the present embodiment satisfying conditional expression (11) can form a large image of a distant subject on the image plane.
[0109] In the variable magnification optical system of the present embodiment, the effect of the present embodiment can be ensured by setting the upper limit of conditional expression (11) to 15.00°. To further ensure the effect of the present embodiment, the upper limit of conditional expression (11) is preferably set to 13.00°, more preferably to 12.00°.
[0110] A small-sized variable magnification optical system of favorable imaging performance can be achieved by the above configurations.
[0111] An optical device of the present embodiment includes a variable magnification optical system configured as described above. This enables achieving an optical device of favorable optical performance.
[0112] A method for manufacturing a variable magnification optical system of the present embodiment includes configuring a variable magnification optical system including, in order from

an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups so that at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied, and that the following conditional expression is satisfied.

[00011] $0.24 < (TL / f1) / (ft / fw) < 0.55$ (1)

where [0113] TL: the distance from a lens surface closest to the object side to the image plane [0114] f1: the focal length of the first lens group [0115] ft: the focal length of the variable magnification optical system in a telephoto end state [0116] fw: the focal length of the variable magnification optical system in a wide-angle end state

[0117] A variable magnification optical system of favorable optical performance can be manufactured by such a method for manufacturing an optical system.

NUMERICAL EXAMPLES

[0118] Examples of the present application will be described below with reference to the drawings.

First Example

[0119] FIG. **1** is a cross-sectional view of a variable magnification optical system of a first example focusing on an object at infinity in the wide-angle end state.

[0120] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having negative refractive power, and a fifth lens group G**5** having positive refractive power.

[0121] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a biconvex positive lens L**12**, and a meniscus-shaped positive lens L**13** convex on the object side.

[0122] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.

[0123] The third lens group G**3** consists of, in order from the object side, an aperture stop S, a biconvex positive lens L**31**, a positive cemented lens composed of a biconvex positive lens L**32** and a meniscus-shaped negative lens L**33** concave on the object side, and a positive cemented lens composed of a meniscus-shaped negative lens L**34** convex on the object side and a biconvex positive lens L**35**.

[0124] The fourth lens group G**4** consists of a negative cemented lens composed of a meniscus-shaped positive lens L**41** concave on the object side and a biconcave negative lens L**42**.

[0125] The fifth lens group G**5** consists of, in order from the object side, a biconvex positive lens L**51**, a negative cemented lens composed of a meniscus-shaped positive lens L**52** concave on the object side and a biconcave negative lens L**53**, a positive cemented lens composed of a meniscus-shaped negative lens L**54** convex on the object side and a biconvex positive lens L**55**, and a meniscus-shaped negative lens L**56** concave on the object side.

[0126] An imaging device (not shown) constructed from CCD. CMOS, or the like is disposed on an image plane I.

[0127] The variable magnification optical system of the present example focuses by moving the fourth lens group G**4** along the optical axis. When focus is shifted from infinity to a nearby object, the fourth lens group G**4** moves from the object side toward the image plane side.

[0128] In the variable magnification optical system of the present example, the fourth lens group G**4** and the fifth lens group G**5** correspond to the subsequent lens group: the fourth lens group G**4** corresponds to the focusing lens group: the fifth lens group G**5** corresponds to the final lens group. The fifth lens group G**5** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.

[0129] Table 1 below shows specifications of the variable magnification optical system of the present example.

[0130] In [General specifications]. TL is the distance from a lens surface closest to the object side to the image plane: fw is the focal length of the whole system in the wide-angle end state: ft is the focal length of the whole system in the telephoto end state: FNOw is the f-number in the wide-angle end state: FNOt is the f-number in the telephoto end state; ww is the semi-field angle (degrees) in the wide-angle end state; ωt is the semi-field angle (degrees) in the telephoto end state: Y is the maximum image height.

[0131] In [Lens specifications], m denotes the numbers of optical surfaces counted from the object side, r the radii of curvature, d the surface-to-surface distances, nd the refractive indices at d-line (wavelength 587.6 nm), and vd the Abbe numbers based on d-line. The radius of curvature r=∞ means a plane. In [Lens specifications], the optical surfaces with "*" are aspherical surfaces.

[0132] In [Aspherical surface data], m denotes the optical surfaces corresponding to aspherical surface data. K the conic constants, and A4 to A12 the aspherical coefficients.

[0133] The aspherical surfaces are expressed by expression (a) below, where y denotes the height in a direction perpendicular to the optical axis, S(y) the distance along the optical axis from the tangent plane at the vertex of an aspherical surface to the aspherical surface at height y (a sag), r the radius of curvature of a reference sphere (paraxial radius of curvature), K the conic constant, and An the nth-order aspherical coefficient. In the examples, the second-order aspherical coefficient A2 is 0. "E-n" means "×10.sup.−n."

[00012]

$$S(y) = (y^2/r)/\{1+(1-K\times y^2/r^2)^{1/2}\} + A4\times y^4 + A6\times y^6 + A8\times y^8 + A10\times y^{10} + A12\times y^{12} \quad (a)$$

[0134] The unit of the focal lengths fW and fT, the radii of curvature r, and the other lengths listed in Table 1 is "mm." However, the values are not limited thereto because the optical performance of a proportionally enlarged or reduced optical system is the same as that of the original optical system.

[0135] The above reference symbols in Table 1 will also be used similarly in the tables of the other examples described below.

TABLE-US-00001 TABLE 1 [General specifications] TL 185.45 fw 28.80 ft 131.00 FNOw 4.11 FNOt 4.12 ωw 38.46 ωt 8.68 Y 21.60 [lens specifications] m r d nd vd 1) 203.5350 2.000 1.90366 31.27 2) 66.2025 10.955 1.59319 67.90 3) −394.6700 0.200 4) 61.5683 6.780 1.75500 52.34 5) 263.3113 D5 *6) 180.9166 1.500 1.82098 42.50 7) 19.6183 6.756 8) −44.0068 1.500 1.83481 42.73 9) 82.0673 0.200 10) 43.9489 4.902 1.80809 22.74 11) −42.7886 0.967 12) −29.1485 1.500 1.81600 46.59 13) −206.5239 D13 14) ∞ 2.000 (aperture stop) *15) 102.6863 2.882 1.59245 66.92 16) −108.3264 0.200 17) 44.1156 5.502 1.59319 67.90 18) −52.1552 1.500 1.85883 30.00 19) −90.3268 3.621 20) 41.9375 1.500 2.00100 29.12 21) 22.4452 7.995 1.55332 71.67 *22) −37.7944 D22 23) −101.0979 2.706 1.94595 17.98 24) −32.6426 1.500 1.77387 47.25 *25) 23.4907 D25 26) 38.2444 9.394 1.59319 67.90 27) −33.7518 0.200 28) −69.6810 7.610 1.78472 25.64 29) −19.0000 1.500 2.00069 25.46 30) 65.6562 0.210 31) 44.8073 1.500 1.90366 31.27 32) 23.5000 10.489 1.69895 30.13 33) −57.9472 5.237 *34) −20.4734 1.500 1.74310 49.44 35) −30.6723 D35 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 3.202E−06 −7.029E−09 2.763E−11 −7.583E−14 1.181E−16 15) 1.0000 −8.531E−06 −1.770E−09 −7.217E−12 3.167E−14 22) 1.0000 6.339E−06 −1.292E−08 3.068E−11 −1.100E−14 25) 1.0000 −6.885E−06 −3.233E−09 1.766E−10 −1.843E−12 34) 1.0000 3.056E−06 8.008E−09 1.421E−10 −4.651E−13 1.075E−15 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 92.73 G2 6 −17.34 G3 14 24.62 G4 23 −26.67 G5 26 96.06 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 2.000 25.493 37.799 2.000 25.493 37.799 D13 37.799 14.305 2.000 37.799 14.305 2.000 D22 2.000 9.389 16.869 2.153 9.804 17.740 D25 21.523 14.134 6.655 21.370 13.720 5.783 D35 17.828 17.828 17.828 17.828 17.828 17.828

[0136] FIG. **2**A shows aberrations of the variable magnification optical system of the first example focusing on an object at infinity in the wide-angle end state: FIG. **2**B shows aberrations of the variable magnification optical system of the first example focusing on an object at infinity in the telephoto end state.
[0137] In the graphs of aberrations, FNO and Y denote f-number and image height, respectively. More specifically, the graph of spherical aberration shows the f-number corresponding to the maximum aperture: the graphs of astigmatism and distortion show the maximum of image height: the graphs of coma aberration show the values of image height. d and g denote d-line and g-line (wavelength 435.8 nm), respectively. In the graph of astigmatism, the solid lines and the broken lines show a sagittal plane and a meridional plane, respectively. The reference symbols in the graphs of aberrations of the present example will also be used in those of the other examples described below.
[0138] The graphs of aberrations suggest that the variable magnification optical system of the present example corrects aberrations appropriately and has high optical performance.
Second Example
[0139] FIG. **3** is a cross-sectional view of a variable magnification optical system of a second example focusing on an object at infinity in the wide-angle end state.
[0140] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having negative refractive power, and a fifth lens group G**5** having positive refractive power.
[0141] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a biconvex positive lens L**12**, and a meniscus-shaped positive lens L**13** convex on the object side.
[0142] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.
[0143] The third lens group G**3** consists of, in order from the object side, an aperture stop S, a biconvex positive lens L**31**, a positive cemented lens composed of a biconvex positive lens L**32** and a meniscus-shaped negative lens L**33** concave on the object side, and a positive cemented lens composed of a meniscus-shaped negative lens L**34** convex on the object side and a biconvex positive lens L**35**.
[0144] The fourth lens group G**4** consists of a negative cemented lens composed of a meniscus-shaped positive lens L**41** concave on the object side and a biconcave negative lens L**42**.
[0145] The fifth lens group G**5** consists of, in order from the object side, a negative cemented lens composed of a biconvex positive lens L**51** and a meniscus-shaped negative lens L**52** concave on the object side, a biconvex positive lens L**53**, and a meniscus-shaped negative lens L**54** concave on the object side.
[0146] An imaging device (not shown) constructed from CCD, CMOS, or the like is disposed on an image plane I.
[0147] The variable magnification optical system of the present example focuses by moving the fourth lens group G**4** along the optical axis. When focus is shifted from infinity to a nearby object, the fourth lens group G**4** moves from the object side toward the image plane side.
[0148] In the variable magnification optical system of the present example, the fourth lens group G**4** and the fifth lens group G**5** correspond to the subsequent lens group: the fourth lens group G**4** corresponds to the focusing lens group: the fifth lens group G**5** corresponds to the final lens group. The fifth lens group G**5** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.
[0149] Table 2 below shows specifications of the variable magnification optical system of the

present example.

TABLE-US-00002 TABLE 2 [General specifications] TL 185.45 fw 28.80 ft 131.00 FNOw 4.12 FNOt 4.12 ωw 38.55 ωt 8.68 Y 21.60 [lens specifications] m r d nd vd 1) 160.9680 2.000 1.85883 30.00 2) 66.6346 10.667 1.49782 82.57 3) −440.7488 0.200 4) 61.6751 6.785 1.75500 52.34 5) 270.2573 D5 *6) 200.0407 1.500 1.82098 42.50 7) 19.4035 6.813 8) −50.3925 1.500 1.81600 46.59 9) 88.0073 0.200 10) 40.5880 4.660 1.80809 22.74 11) −61.3314 1.043 12) −35.5828 1.500 1.77250 49.62 13) −1523.3790 D13 14) ∞ 2.000 (aperture stop) *15) 89.0223 2.817 1.59245 66.92 16) −138.8020 0.200 17) 43.1800 5.721 1.59319 67.90 18) −46.1385 1.500 2.00069 25.46 19) −75.7096 2.760 20) 42.7879 1.500 1.90265 35.77 21) 19.9289 8.552 1.55332 71.67 *22) −37.9809 D22 23) −91.1448 2.782 1.94595 17.98 24) −30.5403 1.500 1.77387 47.25 *25) 23.7535 D25 26) 48.8085 8.210 1.49782 82.57 27) −39.8555 1.500 2.00100 29.12 28) −1151.4031 0.247 29) 78.5798 9.000 1.55298 55.07 30) −35.4446 9.937 *31) −25.9824 1.500 1.74310 49.44 32) −39.1102 D32 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 2.250E−06 −6.521E−09 2.698E−11 −8.238E−14 1.019E−16 15) 1.0000 −8.797E−06 −8.208E−11 −2.286E−11 5.285E−14 22) 1.0000 4.616E−06 −1.129E−08 2.220E−12 2.745E−14 25) 1.0000 −7.596E−06 3.224E−09 −2.256E−11 −6.035E−13 31) 1.0000 −3.031E−06 −7.979E−09 7.173E−11 −2.277E−13 3.068E−16 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 94.25 G2 6 −17.77 G3 14 24.74 G4 23 −26.42 G5 26 76.08 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 2.000 25.602 37.954 2.000 25.602 37.954 D13 37.954 14.352 2.000 37.954 14.352 2.000 D22 2.000 9.302 16.644 2.160 9.726 17.519 D25 21.625 14.323 6.981 21.465 13.899 6.106 D32 25.282 25.282 25.281 25.282 25.282 25.281

[0150] FIG. **4**A shows aberrations of the variable magnification optical system of the second example focusing on an object at infinity in the wide-angle end state; FIG. **4**B shows aberrations of the variable magnification optical system of the second example focusing on an object at infinity in the telephoto end state.

[0151] The graphs of aberrations suggest that the variable magnification optical system of the present example corrects aberrations appropriately and has high optical performance.

Third Example

[0152] FIG. **5** is a cross-sectional view of a variable magnification optical system of a third example focusing on an object at infinity in the wide-angle end state.

[0153] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having positive refractive power, a fifth lens group G**5** having negative refractive power, and a sixth lens group G**6** having positive refractive power.

[0154] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a biconvex positive lens L**12**, and a meniscus-shaped positive lens L**13** convex on the object side.

[0155] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.

[0156] The third lens group G**3** consists of, in order from the object side, an aperture stop S, a biconvex positive lens L**31**, and a meniscus-shaped negative lens L**32** concave on the object side.

[0157] The fourth lens group G**4** consists of, in order from the object side, a meniscus-shaped positive lens L**41** convex on the object side, a biconvex positive lens L**42**, a positive cemented lens composed of a meniscus-shaped negative lens L**43** convex on the object side and a biconvex positive lens L**44**, and a meniscus-shaped negative lens L**45** convex on the object side.

[0158] The fifth lens group G**5** consists of a negative cemented lens composed of a meniscus-shaped negative lens L**51** convex on the object side and a meniscus-shaped positive lens L**52**

convex on the object side.
[0159] The sixth lens group G**6** consists of, in order from the object side, a meniscus-shaped negative lens L**61** concave on the object side and a biconvex positive lens L**62**.
[0160] An imaging device (not shown) constructed from CCD, CMOS, or the like is disposed on an image plane I.
[0161] The variable magnification optical system of the present example focuses by moving the fifth lens group G**5** along the optical axis. When focus is shifted from infinity to a nearby object, the fifth lens group G**5** moves from the object side toward the image plane side.
[0162] In the variable magnification optical system of the present example, the fourth, fifth, and sixth lens groups G**4**, G**5**, and G**6** correspond to the subsequent lens group: the fifth lens group G**5** corresponds to the focusing lens group: the sixth lens group G**6** corresponds to the final lens group. The fourth lens group G**4** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.
[0163] Table 3 below shows specifications of the variable magnification optical system of the present example.
TABLE-US-00003 TABLE 3 [General specifications] TL 178.46 fw 28.84 ft 130.95 FNOw 4.12 FNOt 4.12 ωw 38.54 ωt 8.71 Y 21.60 [lens specifications] m r d nd vd 1) 106.2485 1.200 1.85451 25.15 2) 72.9108 7.265 1.49782 82.57 3) −2566.3273 0.200 4) 73.1525 5.243 1.59319 67.90 5) 311.0755 D5 *6) 407.0508 1.200 1.85108 40.12 7) 26.2159 7.148 8) −51.6266 1.200 1.72916 54.61 9) 51.4576 0.200 10) 45.6463 5.333 1.85451 25.15 11) −83.8936 2.473 *12) −28.9700 1.200 1.49782 82.57 13) −65.5471 D13 14) ∞ 2.000 (aperture stop) 15) 95.8245 4.041 1.59349 67.00 16) −62.8425 0.940 17) −40.3456 1.651 1.87070 40.74 18) −65.9661 D18 *19) 25.9551 4.000 1.51680 64.14 20) 44.4253 0.645 21) 39.9828 5.500 1.59319 67.90 22) −391.0917 1.331 23) 48.6465 1.200 1.90366 31.27 24) 18.3320 7.807 1.59319 67.90 25) −171.4604 0.200 26) 77.7825 1.200 1.69343 53.30 *27) 73.7764 D27 28) 80.7818 1.200 1.95000 29.37 29) 16.7054 3.578 1.94595 17.98 30) 27.6369 D30 *31) −101.4351 1.200 1.85108 40.12 32) −42069.7150 3.381 33) 73.6536 5.500 1.54814 45.51 34) −164.9703 D34 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 2.211E−06 −1.437E−09 1.171E−11 −2.870E−14 5.008E−17 12) 1.0000 −1.225E−07 −1.735E−09 −1.015E−11 19) 1.0000 −2.831E−06 −3.190E−09 −5.738E−12 −8.899E−15 27) 1.0000 1.265E−05 1.948E−08 1.185E−11 2.335E−13 31) 1.0000 −1.999E−06 2.863E−09 −3.559E−12 8.759E−15 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 105.19 G2 6 −24.34 G3 14 134.69 G4 19 35.45 G5 28 −46.01 G6 31 361.54 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 1.500 22.793 38.616 1.500 22.793 38.616 D13 39.116 17.822 2.000 39.116 17.822 2.000 D18 20.867 4.924 2.000 20.867 4.924 2.000 D27 2.529 4.659 10.992 2.905 5.282 12.275 D30 17.618 31.431 28.022 17.242 30.807 26.739 D34 18.793 18.798 18.797 18.793 18.798 18.797
[0164] FIG. **6**A shows aberrations of the variable magnification optical system of the third example focusing on an object at infinity in the wide-angle end state; FIG. **6**B shows aberrations of the variable magnification optical system of the third example focusing on an object at infinity in the telephoto end state.
[0165] The graphs of aberrations suggest that the variable magnification optical system of the present example corrects aberrations appropriately and has high optical performance.
Fourth Example
[0166] FIG. **7** is a cross-sectional view of a variable magnification optical system of a fourth example focusing on an object at infinity in the wide-angle end state.
[0167] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having positive refractive power, a fifth lens group G**5** having negative refractive power,

and a sixth lens group G**6** having negative refractive power.

[0168] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a meniscus-shaped positive lens L**12** convex on the object side, and a meniscus-shaped positive lens L**13** convex on the object side.

[0169] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.

[0170] The third lens group G**3** consists of, in order from the object side, an aperture stop S and a positive cemented lens composed of a biconvex positive lens L**31** and a meniscus-shaped negative lens L**32** concave on the object side.

[0171] The fourth lens group G**4** consists of, in order from the object side, a meniscus-shaped positive lens L**41** convex on the object side, a positive cemented lens composed of a meniscus-shaped positive lens L**42** convex on the object side and a biconvex positive lens L**43**, and a meniscus-shaped negative lens L**44** convex on the object side.

[0172] The fifth lens group G**5** consists of a negative cemented lens composed of a meniscus-shaped negative lens L**51** convex on the object side and a meniscus-shaped positive lens L**52** convex on the object side.

[0173] The sixth lens group G**6** consists of, in order from the object side, a meniscus-shaped positive lens L**61** concave on the object side, a meniscus-shaped negative lens L**62** concave on the object side, and a biconvex positive lens L**63**.

[0174] An imaging device (not shown) constructed from CCD, CMOS, or the like is disposed on an image plane I.

[0175] The variable magnification optical system of the present example focuses by moving the fifth lens group G**5** along the optical axis. When focus is shifted from infinity to a nearby object, the fifth lens group G**5** moves from the object side toward the image plane side.

[0176] In the variable magnification optical system of the present example, the fourth, fifth, and sixth lens groups G**4**, G**5**, and G**6** correspond to the subsequent lens group: the fifth lens group G**5** corresponds to the focusing lens group: the sixth lens group G**6** corresponds to the final lens group. The fourth lens group G**4** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.

[0177] Table 4 below shows specifications of the variable magnification optical system of the present example.

TABLE-US-00004 TABLE 4 [General specifications] TL 179.47 fw 28.84 ft 130.95 FNOw 4.12 FNOt 4.12 ωw 38.54 ωt 8.69 Y 21.60 [lens specifications] m r d nd vd 1) 100.3057 1.200 1.85451 25.15 2) 60.8344 8.099 1.53775 74.70 3) 469.7604 0.200 4) 76.2982 5.766 1.75500 52.34 5) 445.1784 D5 *6) 489.6863 1.200 1.85108 40.12 7) 25.8725 8.554 8) −50.8620 1.200 1.83481 42.72 9) 76.2098 0.200 10) 53.6363 5.772 1.84666 23.80 11) −47.5523 0.904 12) −34.9057 1.200 1.74310 49.44 *13) −135.8499 D13 14) ∞ 4.500 (aperture stop) *15) 63.0236 4.554 1.69343 53.30 16) −58.8213 1.200 1.95000 29.37 17) −207.1161 D17 *18) 33.7325 4.500 1.59319 67.90 19) 153.6733 3.481 20) 33.2491 1.200 1.90110 27.06 21) 23.3148 8.000 1.53775 74.70 22) −73.6961 0.200 23) 53.2656 1.200 1.85108 40.12 *24) 30.8637 D24 25) 104.0299 1.200 2.00069 25.46 26) 18.9870 4.800 1.94595 17.98 27) 39.8976 D27 *28) −103.0331 4.657 1.69343 53.30 29) −40.6980 5.706 30) −30.6104 1.200 1.91082 35.25 31) −216.9426 0.200 32) 55.8746 6.500 1.61266 44.46 33) −211.7306 D33 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 1.488E−06 −5.065E−10 1.818E−12 1.359E−15 13) 1.0000 2.938E−07 −7.289E−10 1.426E−11 −2.828E−14 15) 1.0000 −1.642E−06 9.096E−10 −2.490E−12 18) 1.0000 9.832E−08 −5.129E−09 −2.654E−12 24) 1.0000 1.226E−05 2.280E−08 3.207E−12 1.685E−13 28) 1.0000 −1.332E−06 2.889E−09 2.329E−12 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 97.13 G2 6 −23.47 G3 14 89.27 G4 18 44.88 G5 25 −60.88 G6 28

−3286.39 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 500 23.030 37.587 1.500 23.030 37.587 D13 39.087 17.557 3.000 39.087 17.557 3.000 D17 22.857 6.314 2.000 22.857 6.314 2.000 D24 5.350 6.250 11.401 6.000 7.252 13.341 D27 9.813 25.456 24.618 9.162 24.454 22.679 D33 13.468 13.469 13.458 13.468 13.469 13.458

[0178] FIG. **8**A shows aberrations of the variable magnification optical system of the fourth example focusing on an object at infinity in the wide-angle end state: FIG. **8**B shows aberrations of the variable magnification optical system of the fourth example focusing on an object at infinity in the telephoto end state.

[0179] The graphs of aberrations suggest that the variable magnification optical system of the present example corrects aberrations appropriately and has high optical performance.

Fifth Example

[0180] FIG. **9** is a cross-sectional view of a variable magnification optical system of a fifth example focusing on an object at infinity in the wide-angle end state.

[0181] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having positive refractive power, a fifth lens group G**5** having positive refractive power, a sixth lens group G**6** having negative refractive power, and a seventh lens group G**7** having positive refractive power.

[0182] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a biconvex positive lens L**12**, and a meniscus-shaped positive lens L**13** convex on the object side.

[0183] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.

[0184] The third lens group G**3** consists of, in order from the object side, an aperture stop S, a biconvex positive lens L**31**, and a meniscus-shaped negative lens L**32** concave on the object side.

[0185] The fourth lens group G**4** consists of, in order from the object side, a meniscus-shaped positive lens L**41** convex on the object side and a positive cemented lens composed of a biconvex positive lens L**42** and a meniscus-shaped negative lens L**43** concave on the object side.

[0186] The fifth lens group G**5** consists of a positive cemented lens composed of a meniscus-shaped negative lens L**51** convex on the object side and a biconvex positive lens L**52**, and a meniscus-shaped positive lens L**53** convex on the object side.

[0187] The sixth lens group G**6** consists of a negative cemented lens composed of a meniscus-shaped negative lens L**61** convex on the object side and a meniscus-shaped positive lens L**62** convex on the object side.

[0188] The seventh lens group G**7** consists of, in order from the object side, a meniscus-shaped negative lens L**71** concave on the object side and a meniscus-shaped positive lens L**72** convex on the object side.

[0189] An imaging device (not shown) constructed from CCD, CMOS, or the like is disposed on an image plane I.

[0190] The variable magnification optical system of the present example focuses by moving the sixth lens group G**6** along the optical axis. When focus is shifted from infinity to a nearby object, the sixth lens group G**6** moves from the object side toward the image plane side.

[0191] In the variable magnification optical system of the present example, the fourth, fifth, sixth, and seventh lens groups G**4**, G**5**, G**6**, and G**7** correspond to the subsequent lens group; the sixth lens group G**6** corresponds to the focusing lens group; the seventh lens group G**7** corresponds to the final lens group. The fourth lens group G**4** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.

[0192] Table 5 below shows specifications of the variable magnification optical system of the present example.

TABLE-US-00005 TABLE 5 [General specifications] TL 169.45 fw 28.84 ft 116.40 FNOw 4.12 FNOt 4.12 ωw 38.52 ωt 9.80 Y 21.60 [lens specifications] m r d nd vd 1) 93.2961 1.200 1.85451 25.15 2) 64.7090 8.994 1.49782 82.57 3) −1632.1248 0.200 4) 69.0153 5.266 1.59319 67.90 5) 278.2695 D5 *6) 315.4615 1.200 1.77387 47.25 7) 23.3642 7.183 8) −56.9381 1.200 1.83481 42.73 9) 89.0147 0.200 10) 48.2552 5.210 1.84666 23.80 11) −77.2530 1.839 12) −33.1241 1.500 1.59319 67.90 13) −166.5029 D13 14) ∞ 2.000 (aperture stop) *15) 103.5679 3.610 1.69343 53.30 16) −65.2717 0.920 17) −38.6388 1.605 1.80100 34.92 18) −75.8947 D18 *19) 32.3007 3.500 1.51680 64.14 20) 59.0298 0.200 21) 42.1175 5.000 1.59319 67.90 22) −136.2064 1.741 1.72047 34.71 23) −228.7783 D23 24) 41.7423 1.200 1.85451 25.15 25) 21.6999 6.682 1.49782 82.57 26) −240.2934 0.200 27) 76.7885 2.000 1.85108 40.12 *28) 108.2756 D28 29) 111.2012 1.200 1.95000 29.37 30) 17.1778 3.739 1.94595 17.98 31) 29.4041 D31 *32) −46.3988 1.200 1.85108 40.12 33) −80.8980 0.200 34) 57.3607 5.500 1.57501 41.50 35) 1745.7962 D35 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 1.519E−06 −2.184E−10 1.352E−12 −1.201E−15 9.425E−18 15) 1.0000 −6.645E−07 1.393E−09 −3.960E−12 19) 1.0000 −2.186E−07 −1.597E−09 −1.186E−12 28) 1.0000 1.109E−05 1.403E−08 8.343E−12 1.499E−13 32) 1.0000 −1.684E−06 8.599E−10 3.075E−12 6.087E−16 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 96.71 G2 6 −23.18 G3 14 136.52 G4 19 43.42 G5 24 105.09 G6 29 −43.14 G7 32 469.29 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 1.619 20.213 32.811 1.619 20.213 32.811 D13 33.925 15.331 2.733 33.925 15.331 2.733 D17 18.781 3.212 2.000 18.781 3.212 2.000 D24 2.382 2.449 2.000 2.382 2.449 2.000 D27 2.394 4.128 8.760 2.777 4.750 9.887 D33 20.417 34.186 31.215 20.035 33.564 30.087 D35 15.440 15.449 15.451 15.440 15.449 15.451

[0193] FIG. **10**A shows aberrations of the variable magnification optical system of the fifth example focusing on an object at infinity in the wide-angle end state: FIG. **10**B shows aberrations of the variable magnification optical system of the fifth example focusing on an object at infinity in the telephoto end state.

[0194] The graphs of aberrations suggest that the variable magnification optical system of the present example corrects aberrations appropriately and has high optical performance.

Sixth Example

[0195] FIG. **11** is a cross-sectional view of a variable magnification optical system of a sixth example focusing on an object at infinity in the wide-angle end state.

[0196] The variable magnification optical system of the present example includes, in order from the object side, a first lens group G**1** having positive refractive power, a second lens group G**2** having negative refractive power, a third lens group G**3** having positive refractive power, a fourth lens group G**4** having positive refractive power, a fifth lens group G**5** having positive refractive power, a sixth lens group G**6** having negative refractive power, and a seventh lens group G**7** having positive refractive power.

[0197] The first lens group G**1** consists of, in order from the object side, a positive cemented lens composed of a meniscus-shaped negative lens L**11** convex on the object side and a biconvex positive lens L**12**, and a meniscus-shaped positive lens L**13** convex on the object side.

[0198] The second lens group G**2** consists of, in order from the object side, a meniscus-shaped negative lens L**21** convex on the object side, a biconcave negative lens L**22**, a biconvex positive lens L**23**, and a meniscus-shaped negative lens L**24** concave on the object side.

[0199] The third lens group G**3** consists of, in order from the object side, an aperture stop S, a biconvex positive lens L**31**, and a meniscus-shaped negative lens L**32** concave on the object side.

[0200] The fourth lens group G**4** consists of, in order from the object side, a meniscus-shaped positive lens L**41** convex on the object side and a positive cemented lens composed of a biconvex

positive lens L**42** and a meniscus-shaped negative lens L**43** concave on the object side.
[0201] The fifth lens group G**5** consists of a positive cemented lens composed of a meniscus-shaped negative lens L**51** convex on the object side and a biconvex positive lens L**52**, and a meniscus-shaped positive lens L**53** convex on the object side.
[0202] The sixth lens group G**6** consists of a negative cemented lens composed of a meniscus-shaped negative lens L**61** convex on the object side and a meniscus-shaped positive lens L**62** convex on the object side.
[0203] The seventh lens group G**7** consists of, in order from the object side, a meniscus-shaped negative lens L**71** concave on the object side and a meniscus-shaped positive lens L**72** convex on the object side.
[0204] An imaging device (not shown) constructed from CCD, CMOS, or the like is disposed on an image plane I.
[0205] The variable magnification optical system of the present example focuses by moving the sixth lens group G**6** along the optical axis. When focus is shifted from infinity to a nearby object, the sixth lens group G**6** moves from the object side toward the image plane side.
[0206] In the variable magnification optical system of the present example, the fourth, fifth, sixth, and seventh lens groups G**4**, G**5**, G**6**, and G**7** correspond to the subsequent lens group; the sixth lens group G**6** corresponds to the focusing lens group: the seventh lens group G**7** corresponds to the final lens group. The fourth lens group G**4** corresponds to the lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power.
[0207] Table 6 below shows specifications of the variable magnification optical system of the present example.
TABLE-US-00006 TABLE 6 [General specifications] TL 157.46 fw 28.84 ft 101.85 FNOw 4.12 FNOt 4.12 ωw 38.51 ωt 11.15 Y 21.60 [lens specifications] m r d nd vd 1) 89.9694 1.200 1.85451 25.15 2) 61.8344 8.870 1.49782 82.57 3) −1810.4849 0.200 4) 64.2354 5.370 1.59319 67.90 5) 290.2968 D5 *6) 5724.0693 1.200 1.77387 47.25 7) 22.3009 6.722 8) −51.4759 1.200 1.87070 40.74 9) 89.5799 0.200 10) 48.1451 4.981 1.84666 23.80 11) −65.5885 1.692 12) −29.8981 1.362 1.59319 67.90 13) −78.5606 D13 14) ∞ 2.000 (aperture stop) *15) 120.1934 3.278 1.74310 49.44 16) −65.7245 0.960 17) −35.0667 1.651 1.85026 32.35 18) −62.4547 D18 *19) 29.6539 3.262 1.51680 64.14 20) 48.4068 0.200 21) 35.8637 5.000 1.59319 67.90 22) −160.1358 1.853 1.80000 29.84 23) −240.2036 D23 24) 41.9624 1.200 1.85451 25.15 25) 21.1993 6.047 1.49782 82.57 26) −424.5511 0.200 27) 68.6284 2.079 1.85108 40.12 *28) 114.7292 D28 29) 89.8202 1.200 1.95000 29.37 30) 16.6762 3.424 1.94595 17.98 31) 26.9989 D31 *32) −40.8570 1.200 1.85108 40.12 33) −66.9608 0.200 34) 54.9466 5.500 1.54814 45.79 35) 1434.5246 D35 [Aspherical surface data] m K A4 A6 A8 A10 A12 6) 1.0000 2.611E−06 −9.668E−10 4.188E−13 1.205E−14 −8.027E−18 15) 1.0000 −3.471E−07 1.740E−09 −3.975E−12 19) 1.0000 −3.712E−07 −1.673E−09 −2.490E−12 28) 1.0000 1.466E−05 2.424E−08 2.676E−12 3.610E−13 32) 1.0000 −1.048E−06 5.180E−09 −4.595E−12 1.454E−14 [Focal length data of groups] Groups First surfaces Focal lengths G1 1 90.07 G2 6 −22.46 G3 14 140.83 G4 19 40.35 G5 24 101.24 G6 29 −41.95 G7 32 557.85 [Variable spacing data] At focusing on infinity At focusing nearby Wide-angle Midpoint Telephoto Wide-angle Midpoint Telephoto D5 1.995 19.531 28.874 1.995 19.531 28.874 D13 28.880 11.344 2.000 28.880 11.344 2.000 D18 15.834 2.061 2.000 15.834 2.061 2.000 D23 2.490 2.378 2.000 2.490 2.378 2.000 D28 2.241 4.303 7.661 2.633 4.962 8.708 D31 20.172 31.996 29.078 19.781 31.337 28.030 D35 13.601 13.592 13.628 13.601 13.592 13.628
[0208] FIG. **12**A shows aberrations of the variable magnification optical system of the sixth example focusing on an object at infinity in the wide-angle end state; FIG. **12**B shows aberrations of the variable magnification optical system of the sixth example focusing on an object at infinity in the telephoto end state.
[0209] The graphs of aberrations suggest that the variable magnification optical system of the

present example corrects aberrations appropriately and has high optical performance.
[0210] A variable magnification optical system of favorable optical performance can be achieved according to the above examples.
[0211] Values for the conditional expressions of the examples are listed below.
[0212] TL is the distance from a lens surface closest to the object side to the image plane: fw is the focal length of the variable magnification optical system in a wide-angle end state: ft is the focal length of the variable magnification optical system in a telephoto end state. f1, f2, and f3 are the focal lengths of the first, second, and third lens groups, respectively. fF is the focal length of the focusing lens group: fR is the focal length of the final lens group: fRP is the focal length of a lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power. BFw is the back focal length of the variable magnification optical system focusing on infinity in the wide-angle end state: BFt is the back focal length of the variable magnification optical system focusing on infinity in the telephoto end state. Gw is the distance from the lens surface closest to the object side in the variable magnification optical system in the wide-angle end state to the centroid position of the variable magnification optical system: Gt is the distance from the lens surface closest to the object side in the variable magnification optical system in the telephoto end state to the centroid position of the variable magnification optical system. ωw is the semi-field angle of the variable magnification optical system in the wide-angle end state; ωt is the semi-field angle of the variable magnification optical system in the telephoto end state.
[Values for Conditional Expressions]
TABLE-US-00007 Conditional expressions First Second Third Fourth Fifth Sixth (1) (TL/f1)/ 0.440 0.433 0.374 0.407 0.434 0.495 (ft/fw) (2) f1/(−f2) 5.348 5.304 4.321 4.138 4.172 4.011 (3) f1/f3 3.767 3.809 0.781 1.088 0.708 0.640 (4) f2/fF 0.650 0.673 0.529 0.386 0.537 0.535 (5) |fR|/(−fF) 3.602 2.880 7.858 53.979 10.878 13.297 (6) BFw/fw 0.619 0.878 0.652 0.467 0.535 0.472 (7) BFt/ft 0.136 0.193 0.144 0.103 0.133 0.134 (8) f1/fRP 0.965 1.239 2.967 2.164 2.227 2.232 (9) Gw/Gt 0.937 0.913 0.917 0.939 0.925 0.937 (10) ωw 38.458° 38.547° 38.544° 38.541° 38.523° 38.515° (11) ωt 8.677° 8.678° 8.715° 8.694° 9.795° 11.148°
[0213] The above examples are specific examples of the present invention, and the present invention is not limited thereto. The following features can be appropriately employed unless the optical performance of the variable magnification optical system of the embodiment of the present application is compromised.
[0214] In the variable magnification optical system of the present embodiment, the third lens group need not necessarily include an aperture stop. The position of the aperture stop in the variable magnification optical system of the present embodiment is not limited to any of the positions of the aperture stops S in the variable magnification optical systems of the above examples. The aperture stop in the variable magnification optical system of the present embodiment may be disposed between lenses in the third lens group.
[0215] The variable magnification optical system of the present embodiment may include an optical member, such as a filter, between the image plane and a lens surface closest to the image plane.
[0216] The variable magnification optical system of the present embodiment may include a vibration reduction lens group configured to make a movement including a component in a direction perpendicular to the optical axis to correct an image blur caused by shaky hands. The vibration reduction lens group may be a lens group or a lens subgroup consisting of one or more lens components included in a lens group.
[0217] In the variable magnification optical system of the present embodiment, lens surfaces may be spherical, plane, or aspherical surfaces. Spherical or plane lens surfaces are preferable because they facilitate lens machining, assembling, and adjustment and prevent a decrease in optical performance caused by errors in machining, assembling, and adjustment and because depiction performance does not decrease much when the image plane is shifted.

[0218] An aspherical lens surface may be formed by grinding glass or glass molding with a mold having an aspherical shape, or formed on the surface of resin bonded on a glass surface. In the variable magnification optical system of the present embodiment, lens surfaces may be diffractive surfaces, and lenses may be graded index lenses (GRIN lenses) or plastic lenses.
[0219] Next, a camera including the variable magnification optical system of the present embodiment will be described with reference to FIG. **13**.
[0220] FIG. **13** schematically shows a camera including the variable magnification optical system of the present embodiment.
[0221] The camera **1** is a "mirror-less camera" of an interchangeable lens type including the optical system of the first example as an imaging lens **2**.
[0222] In the camera **1**, light from an object (subject) (not shown) is condensed by the imaging lens **2** and reaches an imaging device **3**. The imaging device **3** converts the light from the subject to image data. When a release button (not shown) is pressed by a user who takes a photograph, the image data is stored in a memory (not shown). In this way, the user can take a picture of the subject with the camera **1**.
[0223] The variable magnification optical system of the first example included in the camera **1** as the imaging lens **2** is a variable magnification optical system of favorable optical performance. Thus the camera **1** can achieve favorable optical performance. A camera configured by including any of the variable magnification optical systems of the second to sixth examples as the imaging lens **2** can have the same effect as the camera **1**.
[0224] Finally, a method for manufacturing a variable magnification optical system of the present embodiment will be outlined with reference to FIG. **14**.
[0225] FIG. **14** is a flowchart outlining a method for manufacturing a variable magnification optical system of the present embodiment. The method for manufacturing a variable magnification optical system of the present embodiment shown in FIG. **14** includes steps S**11** to S**13** below.
[0226] Step S**11**: first, second, and third lens groups and a subsequent lens group are prepared.
[0227] Step S**12**: they are arranged so that at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied.
[0228] Step S**13**: the variable magnification optical system is made to satisfy the following conditional expression.
[00013] $0.24 < (TL / f1) / (ft / fw) < 0.55 \quad (1)$

where [0229] TL: the distance from a lens surface closest to the object side to the image plane [0230] f1: the focal length of the first lens group [0231] ft: the focal length of the variable magnification optical system in a telephoto end state [0232] fw: the focal length of the variable magnification optical system in a wide-angle end state
[0233] An optical system of favorable imaging performance can be manufactured by the method for manufacturing a variable magnification optical system of the present embodiment.
[0234] It should be noted that those skilled in the art can make various changes, substitutions, and modifications without departing from the spirit and scope of the present disclosure.

Claims

1. A variable magnification optical system comprising, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups, at varying magnification, the first and third lens groups being fixed with respect to an image plane, and the spacings between adjacent lens groups being varied, the variable magnification optical system satisfying the following conditional expression.
$0.24 < (TL / f1) / (ft / fw) < 0.55$ where TL: the distance from a lens surface closest to the object side to the image plane f1: the focal length of the first lens group ft: the focal length of the variable

magnification optical system in a telephoto end state fw: the focal length of the variable magnification optical system in a wide-angle end state

2. The variable magnification optical system according to claim 1, wherein the following conditional expression is satisfied. 3. < $f1$ / (-$f2$) < 5.8 where f2: the focal length of the second lens group

3. The variable magnification optical system according to claim 1, wherein the following conditional expression is satisfied. 0.45 < $f1$ / $f3$ < 6. where f3: the focal length of the third lens group

4. The variable magnification optical system according to claim 1, wherein the subsequent lens group includes a focusing lens group having negative refractive power and moving at focusing, and the following conditional expression is satisfied. 0.3 < $f2$ / fF < 1. where f2: the focal length of the second lens group fF: the focal length of the focusing lens group

5. The variable magnification optical system according to claim 1, wherein a final lens group disposed closest to the image plane in the subsequent lens group is fixed with respect to the image plane at varying magnification.

6. The variable magnification optical system according to claim 1, wherein the subsequent lens group includes a focusing lens group having negative refractive power and moving at focusing and a final lens group disposed closest to the image plane, and the following conditional expression is satisfied. 2. < .Math. fR .Math. / (-fF) < 100. where fR: the focal length of the final lens group fF: the focal length of the focusing lens group

7. The variable magnification optical system according to claim 1, wherein the following conditional expression is satisfied. 0.15 < BFw / fw < 0.95 where BFw: the back focal length of the variable magnification optical system focusing on infinity in the wide-angle end state

8. The variable magnification optical system according to claim 1, wherein the following conditional expression is satisfied. 0.08 < BFt / ft < 0.24 where BFt: the back focal length of the variable magnification optical system focusing on infinity in the telephoto end state

9. The variable magnification optical system according to claim 1, wherein the subsequent lens group includes at least one lens group having positive refractive power, and the following conditional expression is satisfied. 0.7 < $f1$ / fRP < 3.4 where fRP: the focal length of a lens group having the strongest refractive power of lens groups included in the subsequent lens group and having positive refractive power

10. The variable magnification optical system according to claim 1, wherein the following conditional expression is satisfied. 0.5 < Gw / Gt < 1.5 where Gw: the distance from the lens surface closest to the object side in the variable magnification optical system in the wide-angle end state to the centroid position of the variable magnification optical system Gt: the distance from the lens surface closest to the object side in the variable magnification optical system in the telephoto end state to the centroid position of the variable magnification optical system

11. An optical device comprising the variable magnification optical system according to claim 1.

12. A method for manufacturing a variable magnification optical system, the method comprising configuring a variable magnification optical system including, in order from an object side, a first lens group having positive refractive power, a second lens group having negative refractive power, a third lens group having positive refractive power, and a subsequent lens group including a plurality of lens groups so that at varying magnification, the first and third lens groups are fixed with respect to an image plane, and the spacings between adjacent lens groups are varied, and the following conditional expression is satisfied. 0.24 < (TL / $f1$) / (ft / fw) < 0.55 where TL: the distance from a lens surface closest to the object side to the image plane f1: the focal length of the first lens group ft: the focal length of the variable magnification optical system in a telephoto end state fw: the focal length of the variable magnification optical system in a wide-angle end state