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

Abstract

A variable magnification optical system has, in order from an object side: a first lens group having positive refractive power; a second lens group having negative refractive power; an aperture stop; a third lens group having positive refractive power; and a rear lens group. Upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group is moved toward the object side, and distances between the lens groups are varied. Upon focusing from an infinitely distant object to a closely distant object, the third lens group is moved along the optical axis. At least a portion of the rear lens group constitutes a vibration reduction lens group having negative refractive power and moveable perpendicular to the optical axis. An optical apparatus and a method of manufacture are also provided.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to a variable magnification optical system, an optical device, and a producing method for the variable magnification optical system.

BACKGROUND ART

[0002] There has been proposed a variable magnification optical system suitable for a photographing camera, an electronic still camera, a video camera or the like, for example, in Japanese Patent application Laid-Open No. 2009-251114 and in Japanese Patent application Laid-Open No. 2010-237455.

PRIOR ART DOCUMENT

Patent Document

[0003] Patent Document 1: Japanese Patent application Laid-Open Gazette No. 2009-251114

[0004] Patent Document 2: Japanese Patent application Laid-Open Gazette No. 2010-237455

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

[0005] However, in the conventional variable magnification optical system as described above, there was a problem that excellent correction of aberrations could not have been realized.

[0006] The present invention is made in view of the above-described problem, and has an object to provide a variable magnification optical system capable of realizing excellent optical performance, an optical apparatus, and a method for manufacturing the variable magnification optical system.

Means for Solving the Problem

[0007] In order to solve the above-mentioned object, according to a first aspect of the present invention, there is provided 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group;

[0008] upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group being moved toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a

distance between the third lens group and the rear lens group being varied; [0009] upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole being moved in the direction of the optical axis; [0010] at least a portion of the rear lens group being moved as a vibration reduction lens group so as to have a component in a direction perpendicular to the optical axis; and [0011] the vibration reduction lens group having negative refractive power.

[0012] Further, according to a second aspect of the present invention, there is provided an optical apparatus equipped with the variable magnification optical system according to the first aspect of the present invention.

[0013] Further, according to a third aspect of the present invention, there is provided 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 rear lens group; [0014] upon zooming from a wide-angle end state to a telephoto end state, at least the first lens group and the rear lens group being moved toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group being varied; [0015] upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole being moved in the direction of the optical axis; [0016] at least a portion of the rear lens group being moved as a vibration reduction lens group to have a component in a direction perpendicular to the optical axis; [0017] the vibration reduction lens group having negative refractive power; and [0018] the following conditional expression being satisfied:

$$0.20 < (-f_{VR})/f_3 < 1.20$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes a focal length of the third lens group.

[0019] Further, according to a fourth aspect of the present invention, there is provided an optical apparatus equipped with the variable magnification optical system according to the third aspect of the present invention.

[0020] Further, according to a fifth aspect of the present invention, there is provided 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group; [0021] the third lens group being composed of a cemented lens constructed by a positive lens cemented with a negative lens; [0022] upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group being moved toward the object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group being varied; [0023] upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole being moved in the direction of the optical axis.

[0024] Further, according to a sixth aspect of the present invention, there is provided an optical apparatus equipped with the variable magnification optical system according to the fifth aspect of the present invention.

[0025] Further, according to a seventh aspect of the present invention, there is provided 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 fourth lens group having positive refractive power; [0026] upon zooming from a wide-angle end state to a telephoto end state, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the fourth lens group being varied; and

[0027] the variable magnification optical system having at least one lens that satisfies the following conditional expressions:

$$1.928 < ndh$$

$$28.60 < vdh$$

where ndh denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the lens, and vdh denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the lens.

[0028] Further, according to an eighth aspect of the present invention, there is provided an optical apparatus equipped with the variable magnification optical system according to the seventh aspect of the present invention.

[0029] Further, according to a ninth aspect of the present invention, there is provided a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group;

[0030] the method comprising the steps of: [0031] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group is moved toward an object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group are varied; [0032] constructing such that, upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole is moved in the direction of the optical axis; [0033] constructing such that at least a portion of the rear lens group is moved as a vibration reduction lens group so as to have a component in a direction perpendicular to the optical axis; and [0034] constructing the vibration reduction lens group to have negative refractive power.

[0035] Further, according to a tenth aspect of the present invention, there is provided a method for manufacturing 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 rear lens group; [0036] the method comprising the steps of: [0037] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, at least the first lens group and the rear lens group are moved toward an object side, and a distance between the first lens group and the rear lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group are varied; [0038] constructing such that, upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole is moved in the direction of the optical axis; [0039] constructing such that at least a portion of the rear lens group is moved as a vibration reduction lens group to have a component in a direction perpendicular to the optical axis; [0040] constructing the vibration reduction lens group to have negative refractive power; and constructing the third lens group and the vibration reduction lens group to satisfy the following conditional expression:

$$0.20 < (-f_{VR})/f_3 < 1.20$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes a focal length of the third lens group.

[0041] Further, according to an eleventh aspect of the present invention, there is provided a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group having positive refractive power; [0042] the method comprising the steps of: [0043] constructing such that the third lens group is composed of a cemented lens constructed by a positive lens cemented with a negative lens; [0044] constructing such that, upon zooming from a wide-angle end

state to a telephoto end state, at least a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group are varied; and [0045] constructing such that, upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole is moved in the direction of the optical axis.

[0046] Further, according to a twelfth aspect of the present invention, there is provided 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 fourth lens group having positive refractive power; [0047] constructing the variable magnification optical system to have at least one lens that satisfies the following conditional expressions:

$$1.928 < ndh$$

$$28.60 < vdh$$

where ndh denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the lens, and vdh denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the lens; and [0048] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the fourth lens group are varied.

Effect of the Invention

[0049] According to the first to the sixth aspects and the ninth to the eleventh aspects of the present invention, there are provided a variable magnification which has high variable magnification ratio, is compact and has excellent optical performance, an optical apparatus, and a method for manufacturing a variable magnification optical system.

[0050] According to the seventh, eighth and twelfth fourth aspects of the present invention, there are provided a variable magnification optical system which is compact and has excellent optical performance, an optical apparatus, and a method for manufacturing a variable magnification optical system.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0051] FIGS. 1A, 1B and 1C are sectional views showing a variable magnification optical system according to a First Example that is common to a first to third embodiments of the present application, in which FIG. 1A shows sectional view in a wide-angle end state, FIG. 1B shows sectional view in an intermediate focal length state, and FIG. 1C shows sectional view in a telephoto end state.

[0052] FIGS. 2A, 2B and 2C are graphs showing various aberrations of the variable magnification optical system according to the First Example of the present application upon focusing on an infinite distance object, in which FIG. 2A shows various aberrations in the wide-angle end state, FIG. 2B shows various aberrations in the intermediate focal length state, and FIG. 2C shows various aberrations in the telephoto end state.

[0053] FIGS. 3A and 3B are graphs showing meridional transverse aberration of the variable magnification optical system according to the First Example of the present application upon focusing on an infinitely distant object and conducting vibration reduction, in which FIG. 3A shows meridional transverse aberration in the wide-angle end state, and FIG. 3B shows meridional transverse aberration in the telephoto end state.

[0054] FIGS. 4A, 4B and 4C are sectional views showing a variable magnification optical system

according to a Second Example that is common to the first to third embodiments of the present application, in which FIG. 4A shows sectional view in a wide-angle end state, FIG. 4B shows sectional view in an intermediate focal length state, and FIG. 4C shows sectional view in a telephoto end state.

[0055] FIGS. 5A, 5B and 5C are graphs showing various aberrations of the variable magnification optical system according to the Second Example of the present application upon focusing on an infinitely distant object, in which FIG. 5A shows various aberrations in the wide-angle end state, FIG. 5B shows various aberrations in the intermediate focal length state, and FIG. 5C shows various aberrations in the telephoto end state.

[0056] FIGS. 6A and 6B are graphs showing meridional transverse aberration of the variable magnification optical system according to the Second Example of the present application upon focusing on an infinitely distant object and conducting vibration reduction, in which FIG. 6A shows meridional transverse aberration in the wide-angle end state, and FIG. 6B shows meridional transverse aberration in the telephoto end state.

[0057] FIGS. 7A, 7B and 7C are sectional views showing a variable magnification optical system according to a Third Example that is common to the first to third embodiments of the present application, in which FIG. 7A shows sectional view in a wide-angle end state, FIG. 7B shows sectional view in an intermediate focal length state, and FIG. 7C shows sectional view in a telephoto end state.

[0058] FIGS. 8A, 8B and 8C are graphs showing various aberrations of the variable magnification optical system according to the Third Example of the present application upon focusing on an infinitely distant object, in which FIG. 8A shows various aberrations in the wide-angle end state, FIG. 8B shows various aberrations in the intermediate focal length state, and FIG. 8C shows various aberrations in the telephoto end state.

[0059] FIGS. 9A and 9B are graphs showing meridional transverse aberration of the variable magnification optical system according to the Third Example of the present application upon focusing on an infinitely distant object and conducting vibration reduction, in which FIG. 9A shows meridional transverse aberration in the wide-angle end state, and FIG. 9B shows meridional transverse aberration in the telephoto end state.

[0060] FIGS. 10A, 10B and 10C are sectional views showing a variable magnification optical system according to a Fourth Example of the fourth embodiment of the present application, in which FIG. 10A shows sectional view in a wide-angle end state, FIG. 10B shows sectional view in an intermediate focal length state, and FIG. 10C shows sectional view in a telephoto end state.

[0061] FIGS. 11A, 11B and 11C are graphs showing various aberrations of the variable magnification optical system according to the Fourth Example of the present application upon focusing on an infinitely distant object, in which FIG. 11A shows various aberrations in the wide-angle end state, FIG. 11B shows various aberrations in the intermediate focal length state, and FIG. 11C shows various aberrations in the telephoto end state.

[0062] FIGS. 12A, 12B and 12C are sectional views showing a variable magnification optical system according to a Fifth Example of the fourth embodiment of the present application, in which FIG. 12A shows sectional view in a wide-angle end state, FIG. 12B shows sectional view in an intermediate focal length state, and FIG. 12C shows sectional view in a telephoto end state.

[0063] FIGS. 13A, 13B and 13C are graphs showing various aberrations of the variable magnification optical system according to the Fifth Example of the present application upon focusing on an infinitely distant object, in which FIG. 13A shows various aberrations in the wide-angle end state, FIG. 13B shows various aberrations in the intermediate focal length state, and FIG. 13C shows various aberrations in the telephoto end state.

[0064] FIGS. 14A, 14B and 14C are sectional views showing a variable magnification optical system according to a Sixth Example the fourth embodiment of the present application, in which FIG. 14A shows sectional view in a wide-angle end state, FIG. 14B shows sectional view in an

intermediate focal length state, and FIG. **14C** shows sectional view in a telephoto end state.

[0065] FIGS. **15A**, **15B** and **15C** are graphs showing various aberrations of the variable magnification optical system according to the Sixth Example of the present application upon focusing on an infinitely distant object, in which FIG. **15A** shows various aberrations in the wide-angle end state, FIG. **15B** shows various aberrations in the intermediate focal length state, and FIG. **15C** shows various aberrations in the telephoto end state.

[0066] FIGS. **16A**, **16B** and **16C** are sectional views showing a variable magnification optical system according to a Seventh Example the fourth embodiment of the present application, in which FIG. **16A** shows sectional view in a wide-angle end state, FIG. **16B** shows sectional view in an intermediate focal length state, and FIG. **16C** shows sectional view in a telephoto end state.

[0067] FIGS. **17A**, **17B** and **17C** are graphs showing various aberrations of the variable magnification optical system according to the Seventh Example of the present application upon focusing on an infinitely distant object, in which FIG. **17A** shows various aberrations in the wide-angle end state, FIG. **17B** shows various aberrations in the intermediate focal length state, and FIG. **17C** shows various aberrations in the telephoto end state.

[0068] FIGS. **18A**, **18B** and **18C** are sectional views showing a variable magnification optical system according to a Eighth Example the fourth embodiment of the present application, in which FIG. **18A** shows sectional view in a wide-angle end state, FIG. **18B** shows sectional view in an intermediate focal length state, and FIG. **18C** shows sectional view in a telephoto end state.

[0069] FIGS. **19A**, **19B** and **19C** are graphs showing various aberrations of the variable magnification optical system according to the Eighth Example of the present application upon focusing on an infinitely distant object, in which FIG. **19A** shows various aberrations in the wide-angle end state, FIG. **19B** shows various aberrations in the intermediate focal length state, and FIG. **19C** shows various aberrations in the telephoto end state.

[0070] FIG. **20** is a view showing a configuration of a camera equipped with the variable magnification optical system according to the first to fourth embodiments.

[0071] FIG. **21** is a flowchart schematically explaining a method for manufacturing the variable magnification optical system according to the first embodiment of the present application.

[0072] FIG. **22** is a flowchart schematically explaining a method for manufacturing the variable magnification optical system according to the second embodiment of the present application.

[0073] FIG. **23** is a flowchart schematically explaining a method for manufacturing the variable magnification optical system according to the third embodiment of the present application.

[0074] FIG. **24** is a flowchart schematically explaining a method for manufacturing the variable magnification optical system according to the fourth embodiment of the present application.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0075] The variable magnification optical system, the optical apparatus and the method for manufacturing the variable magnification optical system according to the first embodiment of the present application is explained below.

[0076] The variable magnification optical system according to the first embodiment of the present application comprises, in order from an object side: a first lens group having positive refractive power; a second lens group having negative refractive power; an aperture stop; a third lens group having positive refractive power; and a rear lens group; [0077] upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group being moved toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group being varied; [0078] upon focusing on from an infinite distant object to a close distant object, the third lens group as a whole being moved in the direction of the optical axis; [0079] at least a portion of the rear lens group being moved as a vibration reduction lens group so as to have a component in a direction perpendicular to the optical axis; and [0080] the vibration reduction lens group having negative refractive power.

[0081] In the variable magnification optical system according to the first embodiment of the present application, the third lens group is disposed in the neighborhood of the aperture stop, and focusing on from an infinite distant object to a close distant object, is carried out by moving the third lens group as a whole in the direction of the optical axis. Due to such configuration, variation in curvature of field can be suppressed upon focusing a closely distant object, so it is preferable.

[0082] In the variable magnification optical system according to the first embodiment of the present application, at least a portion of the rear lens groups is moved, as a vibration reduction lens group, to have a component in a direction perpendicular to the optical axis, and the vibration reduction lens group has negative refractive power. Due to this configuration, correction of image blur upon camera shake being caused, that is, vibration reduction, can be conducted. Further, vibration reduction can be conducted by a small-sized lens group, so a mechanism for the vibration reduction can be made downsized and small in weight, thereby a lens barrel being able to be downsized. It is preferable.

[0083] Due to the above mentioned configuration, a variable magnification optical system having high zoom ratio, being downsized, and having excellent optical performance can be realized.

[0084] In the variable magnification optical system according to the first embodiment of the present application, it is preferable that the following conditional expression (1) is satisfied:

$$[00001] \quad 0.6 < f_1 / f_3 < 2.6 \quad (1)$$

where f_1 denotes a focal length of the first lens group, and f_3 denotes a focal length of the third lens group.

[0085] The conditional expression (1) defines the focal length of the first lens group relative to the focal length of the third lens group. With satisfying the conditional expression (1), the variable magnification optical system according to the first embodiment of the present application is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and spherical aberration in the telephoto end state.

[0086] When the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the first embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (1) to 2.50.

[0087] On the other hand, when the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the first embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group increases. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0088] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (1) to 0.40.

[0089] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that the following conditional expression (2) is satisfied:

$$[00002] \quad 5. < f_1 / (-f_2) < 10. \quad (2)$$

where f_1 denotes the focal length of the first lens group, and f_2 denotes a focal length of the second lens group.

[0090] The conditional expression (2) defines the focal length of the first lens group relative to the focal length of the second lens group. With satisfying the conditional expression (2), the variable magnification optical system according to the first embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing in the wide-angle end state and spherical aberration in the telephoto end state.

[0091] When the value of $f_1/(-f_2)$ of the conditional expression (2) of the variable magnification optical system according to the first embodiment of the present application is equal to or exceeds

the upper limit, refractive power of the second lens group becomes large, and it becomes difficult to correct curvature of field in the wide-angle end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (2) to 8.00.

[0092] On the other hand, when the value of $f1/(-f2)$ of the conditional expression (2) of the variable magnification optical system according to the first embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group becomes large. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0093] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (2) to 6.00.

[0094] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that the following conditional expression (3) is satisfied:

$$0.20 < (-f_{VR})/f_3 < 1.20 \quad (3)$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes the focal length of the third lens group.

[0095] The conditional expression (3) defines the focal length of the vibration reduction lens group relative to the focal length of the third lens group. With satisfying the conditional expression (3), the variable magnification optical system according to the first embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and eccentric coma aberration upon conducting the vibration reduction.

[0096] When the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the first embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (3) to 1.00.

[0097] On the other hand, when the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the first embodiment of the present application is equal to or falls below the lower limit, refractive power of the vibration reduction lens group increases. Thus, eccentric coma aberration is generated upon conducting the vibration reduction, so that it is not desirable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (3) to 0.40.

[0098] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that the following conditional expression (4) is satisfied:

$$0.1 < (-f_2)/f_3 < 0.38 \quad (4)$$

where f_2 denotes the focal length of the second lens group, and f_3 denotes the focal length of the third lens group.

[0099] The conditional expression (4) defines the focal length of the second lens group relative to the focal length of the third lens group. The variable magnification optical system according to the first embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and curvature of field in the wide-angle end state, by satisfying the conditional expression (4).

[0100] When the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the first embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It

is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (4) to 0.36.

[0101] On the other hand, when the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the first embodiment of the present application is equal to or falls below the lower limit, refractive power of the second lens group increases. Thus, it becomes difficult to correct curvature of field in the wide-angle end state, so that it is not desirable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (4) to 0.15.

[0102] In the variable magnification optical system according to the first embodiment of the present application, it is preferable that the following conditional expression (5) is satisfied:

$$[00004] \quad 0.42 < f_3 / f_R < 0.8 \quad (5)$$

where f_3 denotes the focal length of the third lens group, and f_R denotes a focal length of the rear lens group in the wide-angle end state.

[0103] The conditional expression (5) defines the focal length of the rear lens group in the wide-angle end state relative to the focal length of the third lens group. Incidentally, in a case where the rear lens group is composed of a plurality of lens groups, f_R denotes a composite focal length of the plurality of lens groups. With satisfying the conditional expression (5), the variable magnification optical system according to the first embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and eccentric coma aberration upon conducting the vibration reduction.

[0104] When the value of f_3/f_R of the conditional expression (5) of the variable magnification optical system according to the first embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (5) to 1.00.

[0105] On the other hand, when the value of f_3/f_R of the conditional expression (5) of the variable magnification optical system according to the first embodiment of the present application is equal to or falls below the lower limit, eccentric coma aberration is generated upon conducting the vibration reduction, so that it is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (5) to 0.40.

[0106] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that the vibration reduction lens group is composed of a cemented lens constructed by a positive lens cemented with a negative lens. By this configuration, eccentric coma aberration generated upon conducting the vibration reduction can be corrected superbly.

[0107] In the variable magnification optical system according to the first embodiment of the present application, it is preferable that the first lens group has a negative lens that satisfies the following conditional expression (6):

$$[00005] \quad 1.9 < n_{d1} \quad (6)$$

where n_{d1} denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group.

[0108] The conditional expression (6) defines refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group. With satisfying the conditional expression (6), the variable magnification optical system according to the first embodiment of the present invention is capable of correcting superbly spherical aberration in the telephoto end state.

[0109] When the value of n_{d1} of the conditional expression (6) of the variable magnification

optical system according to the first embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to correct spherical aberration in the telephoto end state, so that it is not desirable.

[0110] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (6) to 1.92.

[0111] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the second lens group is moved in the direction of the optical axis. With taking such a configuration, curvature of field can be corrected superbly.

[0112] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the third lens group is moved in the direction of the optical axis. With taking such a configuration, spherical aberration can be corrected superbly.

[0113] Further, in the variable magnification optical system according to the first embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the first lens group is moved in the direction of the optical axis. With taking such a configuration, higher zoom ratio can be attained.

[0114] The optical apparatus of the present application, is characterized in the provision of the variable magnification optical system according to the first embodiment having the above described configuration. Owing to this, an optical apparatus having high zoom ratio, being downsized and having superb optical performance, can be realized.

[0115] The method for manufacturing the variable magnification optical system according to the first embodiment of the present application is a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group; [0116] the method being characterized in comprising the steps of: [0117] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group is moved toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group being varied; [0118] constructing such that upon focusing on from an infinitely distant object to a close distant object, the third lens group as a whole is moved in the direction of the optical axis; [0119] constructing such that at least a portion of the rear lens group is moved as a vibration reduction lens group so as to have a component in a direction perpendicular to the optical axis; and [0120] constructing the vibration reduction lens group to have negative refractive power.

[0121] By such a method, it is possible to manufacture a magnification variable optical system that has high zoom ratio, is downsized and has superb optical performance.

[0122] Next, the variable magnification optical system, the optical apparatus and the method for manufacturing the variable magnification optical system according to the second embodiment of the present application is explained below.

[0123] The variable magnification optical system according to the second embodiment of the present application comprises, 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 rear lens group; [0124] upon zooming from a wide-angle end state to a telephoto end state, at least the first lens group and the rear lens group being moved toward an object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group being varied; [0125] upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole being moved in the direction of the optical axis; [0126] at least a portion of the rear lens group being moved as a vibration reduction lens

group to have a component in a direction perpendicular to the optical axis; [0127] the vibration reduction lens group having negative refractive power; and [0128] the following conditional expression (3) being satisfied:

$$[00006] \ 0.2 < (-f_{VR}) / f_3 < 1.2 \quad (3)$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes a focal length of the third lens group.

[0129] In the variable magnification optical system according to the second embodiment of the present application, upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis. Due to such a configuration, variation in curvature of field upon focusing a closely distant object can be preferably suppressed.

[0130] In the variable magnification optical system according to the second embodiment of the present application, at least a portion that is a portion of the rear lens group is moved as a vibration reduction lens group to have a component in a direction perpendicular to the optical axis, and the vibration reduction lens group has negative refractive power. Due to such configuration, image blur upon camera shake being caused can be corrected, that is, vibration reduction can be effected. Further more, since vibration reduction can be conducted by downsized lens group, the vibration reduction mechanism can be downsized and made small in weight, so that the lens barrel can be downsized preferably.

[0131] The conditional expression (3) defines a focal length of the vibration reduction lens group relative to the focal length of the third lens group. The variable magnification optical system according to the second embodiment of the present application is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and eccentric coma aberration upon conducting the vibration reduction.

[0132] When the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the second embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (3) to 1.00.

[0133] On the other hand, when the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, refractive power of the vibration reduction lens group increases. Thus, eccentric coma aberration is generated upon conducting the vibration reduction, so that it is not desirable.

[0134] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (3) to 0.40.

[0135] Due to the above configuration, a variable magnification optical system that has high zoom ratio, is downsized and has superb optical performance, can be realized.

[0136] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that the following conditional expression (4) is satisfied:

$$[00007] \ 0.1 < (-f_2) / f_3 < 0.38 \quad (4)$$

where f_2 denotes the focal length of the second lens group, and f_3 denotes the focal length of the third lens group.

[0137] The conditional expression (4) defines the focal length of the second lens group relative to the focal length of the third lens group. The variable magnification optical system according to the second embodiment of the present application is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and curvature of field in the

wide-angle end state.

[0138] When the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the second embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (4) to 0.36.

[0139] On the other hand, when the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, refractive power of the second lens group increases. Thus, it becomes difficult to correct curvature of field in the wide-angle end state, so that it is not desirable.

[0140] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (4) to 0.15.

[0141] In the variable magnification optical system according to the second embodiment of the present application, it is preferable that the following conditional expression (1) is satisfied:

$$[00008] \quad 0.6 < f_1 / f_3 < 2.6 \quad (1)$$

where f_1 denotes a focal length of the first lens group, and f_3 denotes a focal length of the third lens group.

[0142] The conditional expression (1) defines the focal length of the first lens group relative to the focal length of the third lens group. With satisfying the conditional expression (1), the variable magnification optical system according to the second embodiment of the present application is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and spherical aberration in the telephoto end state.

[0143] When the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the second embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (1) to 2.50.

[0144] On the other hand, when the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group increases. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0145] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (1) to 0.40.

[0146] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that the following conditional expression (2) is satisfied:

$$[00009] \quad 5. < f_1 / (-f_2) < 10. \quad (2)$$

where f_1 denotes the focal length of the first lens group, and f_2 denotes a focal length of the second lens group.

[0147] The conditional expression (2) defines the focal length of the first lens group relative to the focal length of the second lens group. With satisfying the conditional expression (2), the variable magnification optical system according to the second embodiment of the present invention is capable of correcting superbly curvature of field in the wide-angle end state and spherical aberration in the telephoto end state.

[0148] When the value of $f_1/(-f_2)$ of the conditional expression (2) of the variable magnification

optical system according to the second embodiment of the present application is equal to or exceeds the upper limit, refractive power of the second lens group becomes large, and thereby it becomes difficult to correct curvature of field in the wide-angle end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (2) to 8.00.

[0149] On the other hand, when the value of $f1/(-f2)$ of the conditional expression (2) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group becomes large. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0150] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (2) to 6.00.

[0151] In the variable magnification optical system according to the second embodiment of the present application, it is preferable that the following conditional expression (5) is satisfied:

$$[00010] \quad 0.42 < f3 / fR < 0.8 \quad (5)$$

where $f3$ denotes the focal length of the third lens group, and fR denotes a focal length of the rear lens group in the wide-angle end state.

[0152] The conditional expression (5) defines the focal length of the rear lens group in the wide-angle end state relative to the focal length of the third lens group. Incidentally, in a case where the rear lens group is composed of a plurality of lens groups, fR denotes a composite focal length of the plurality of lens groups. With satisfying the conditional expression (5), the variable magnification optical system according to the second embodiment of the present application is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and eccentric coma aberration upon conducting the vibration reduction.

[0153] When the value of $f3/fR$ of the conditional expression (5) of the variable magnification optical system according to the second embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (5) to 1.00.

[0154] On the other hand, when the value of $f3/fR$ of the conditional expression (5) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, refractive power of the rear lens group becomes large. Owing to this, eccentric coma aberration is generated upon conducting the vibration reduction, so that it is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (5) to 0.40.

[0155] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that the vibration reduction lens group is composed of a cemented lens constructed by a positive lens cemented with a negative lens. By this configuration, eccentric coma aberration generated upon conducting the vibration reduction can be corrected superbly.

[0156] In the variable magnification optical system according to the second embodiment of the present application, it is preferable that the first lens group has a negative lens that satisfies the following conditional expression (6):

$$[00011] \quad 1.9 < nd1 \quad (6)$$

where $nd1$ denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group.

[0157] The conditional expression (6) defines refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group. With satisfying the conditional expression (6), the variable magnification optical system according to the second embodiment of the present invention is capable of correcting superbly spherical aberration in the telephoto end state.

[0158] When the value of $nd1$ of the conditional expression (6) of the variable magnification optical system according to the second embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to correct spherical aberration in the telephoto end state, so that it is not desirable.

[0159] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (6) to 1.92.

[0160] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the second lens group is moved in the direction of the optical axis. With taking such a configuration, curvature of field can be corrected superbly.

[0161] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the third lens group is moved in the direction of the optical axis. With taking such a configuration, spherical aberration can be corrected superbly.

[0162] Further, in the variable magnification optical system according to the second embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the first lens group is moved in the direction of the optical axis. With taking such a configuration, higher zoom ratio can be attained.

[0163] The optical apparatus of the present application, is characterized in the provision of the variable magnification optical system according to the second embodiment having the above described configuration. Owing to this, an optical apparatus having high zoom ratio, being downsized and having superb optical performance, can be realized.

[0164] The method for manufacturing the variable magnification optical system according to the second embodiment of the present application is a method for manufacturing 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 rear lens group, and being characterized in comprising the steps of: [0165] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, at least the first lens group and the rear lens group are moved toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group are varied; [0166] constructing such that, upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis, [0167] constructing such that at least a portion of the rear lens group is moved as a vibration reduction lens group so as to have a component in a direction perpendicular to the optical axis; [0168] constructing the vibration reduction lens group to have negative refractive power; and [0169] constructing such that the third lens group and the rear lens group satisfy the following conditional expression (3):

$$[00012] \quad 0.2 < (-f_{VR}) / f_3 < 1.2 \quad (3)$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes a focal length of the third lens group.

[0170] By such a method, it is possible to manufacture a variable magnification optical system that has high zoom ratio, is downsized and has superb optical performance.

[0171] Next, the variable magnification optical system, the optical apparatus and the method for manufacturing the variable magnification optical system according to the third embodiment of the

present application is explained below.

[0172] The variable magnification optical system according to the third embodiment of the present application comprises, in order from an object side: a first lens group having positive refractive power; a second lens group having negative refractive power; an aperture stop; a third lens group having positive refractive power and a rear lens group, the third lens group being composed of a cemented lens constructed by a positive lens cemented with a negative lens; [0173] upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group being moved toward an object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group being varied; and [0174] upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole being moved in the direction of the optical axis.

[0175] In the variable magnification optical system according to the third embodiment of the present application, focusing on from an infinitely distant object to a closely distant object, is carried out by moving, as a whole in the direction of the optical axis, the third lens group that is disposed in the neighborhood of the aperture stop. Due to such a configuration, variation in curvature of field upon focusing on a closely distant object can be preferably suppressed. Moreover, the third lens group is composed of a cemented lens constructed by a positive lens cemented with a negative lens, and thereby variation in spherical aberration upon focusing on the closely distant object as well as variation in longitudinal chromatic aberration can be suppressed, so that it is preferable.

[0176] By such configuration, a variable magnification optical system that has high zoom ratio, is downsized and has superb optical performance, can be realized.

[0177] In the variable magnification optical system according to the third embodiment of the present application, it is preferable that the following conditional expression (5) is satisfied:

$$[00013] \quad 0.42 < f_3 / f_R < 0.8 \quad (5)$$

where f_3 denotes the focal length of the third lens group, and f_R denotes a focal length of the rear lens group in the wide-angle end state.

[0178] The conditional expression (5) defines the focal length of the rear lens group in the wide-angle end state relative to the focal length of the third lens group. Incidentally, in a case where the rear lens group is composed of a plurality of lens groups, f_R denotes a composite focal length of the plurality of lens groups. With satisfying the conditional expression (5), the variable magnification optical system according to the third embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state. Further, in a case where the variable magnification optical system according to the third embodiment of the present application is configured to carry out vibration reduction, it is possible to correct superbly eccentric coma aberration upon conducting the vibration reduction.

[0179] When the value of f_3/f_R of the conditional expression (5) of the variable magnification optical system according to the third embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (5) to 1.00.

[0180] On the other hand, when the value of f_3/f_R of the conditional expression (5) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, refractive power of the rear lens group becomes large. Owing to this, in the case where the variable magnification optical system according to the third embodiment of the present invention is configured to conduct the vibration reduction, eccentric coma aberration

is generated upon conducting the vibration reduction, so that it is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (5) to 0.40.

[0181] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that the following conditional expression (2) is satisfied:

$$[00014] \quad 5. < f_1 / (-f_2) < 10. \quad (2)$$

where f_1 denotes a focal length of the first lens group, and f_2 denotes a focal length of the second lens group.

[0182] The conditional expression (2) defines the focal length of the first lens group relative to the focal length of the second lens group. With satisfying the conditional expression (2), the variable magnification optical system according to the third embodiment of the present application is capable of correcting superbly curvature of field in the wide-angle end state and spherical aberration in the telephoto end state.

[0183] When the value of $f_1/(-f_2)$ of the conditional expression (2) of the variable magnification optical system according to the third embodiment of the present application is equal to or exceeds the upper limit, refractive power of the second lens group becomes large, and it becomes difficult to correct curvature of field in the wide-angle end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (2) to 8.00.

[0184] On the other hand, when the value of $f_1/(-f_2)$ of the conditional expression (2) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group becomes large. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0185] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (2) to 6.00.

[0186] In the variable magnification optical system according to the third embodiment of the present application, it is preferable that the following conditional expression (1) is satisfied:

$$[00015] \quad 0.6 < f_1 / f_3 < 2.6 \quad (1)$$

where f_1 denotes the focal length of the first lens group, and f_3 denotes a focal length of the third lens group.

[0187] The conditional expression (1) defines the focal length of the first lens group relative to the focal length of the third lens group. With satisfying the conditional expression (1), the variable magnification optical system according to the third embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and spherical aberration in the telephoto end state.

[0188] When the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the third embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (1) to 2.50.

[0189] On the other hand, when the value of f_1/f_3 of the conditional expression (1) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, refractive power of the first lens group increases. Thus, spherical aberration is generated in the telephoto end state, so that it is not desirable.

[0190] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (1) to 0.40.

[0191] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that the following conditional expression (4) is satisfied:

[00016] $0.10 < (-f_2)/f_3 < 0.38$ (4)

where f_2 denotes the focal length of the second lens group, and f_3 denotes the focal length of the third lens group.

[0192] The conditional expression (4) defines the focal length of the second lens group relative to the focal length of the third lens group. The variable magnification optical system according to the third embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and curvature of field in the wide-angle end state, by satisfying the conditional expression (4).

[0193] When the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the third embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (4) to 0.36.

[0194] On the other hand, when the value of $(-f_2)/f_3$ of the conditional expression (4) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, refractive power of the second lens group increases. Thus, it becomes difficult to correct curvature of field in the wide-angle end state, so that it is not desirable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (4) to 0.15.

[0195] In the variable magnification optical system according to the third embodiment of the present application, it is preferable that the first lens group has a negative lens that satisfies the following conditional expression (6):

[00017] $1.9 < nd_1$ (6)

where nd_1 denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group.

[0196] The conditional expression (6) defines refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group. With satisfying the conditional expression (6), the variable magnification optical system according to the third embodiment of the present invention is capable of correcting superbly spherical aberration in the telephoto end state.

[0197] When the value of nd_1 of the conditional expression (6) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to correct spherical aberration in the telephoto end state, so that it is not desirable.

[0198] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (6) to 1.92.

[0199] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that a lens that is at least a portion of the rear lens group is moved to have a component in a direction perpendicular to the optical axis, and the vibration reduction lens has negative refractive power. By such configuration, it is possible to correct image blur upon generating camera shake, that is, to conduct vibration reduction. Moreover, the vibration reduction can be conducted by a lens group having small diameter, so the vibration reduction mechanism can be downsized and small in weight. Thus, a lens barrel can be downsized. This is preferable.

[0200] Furthermore, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that the vibration reduction lens group is constructed by a cemented lens composed of a positive lens and a negative lens. Due to such configuration, eccentric coma aberration upon conducting the vibration reduction can be corrected

excellently.

[0201] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that the following conditional expression (3) is satisfied:

$$[00018] \ 0.20 < (-f_{VR}) / f_3 < 1.2 \quad (3)$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes the focal length of the third lens group.

[0202] The conditional expression (3) defines the focal length of the vibration reduction lens group relative to the focal length of the third lens group. With satisfying the conditional expression (3), the variable magnification optical system according to the third embodiment of the present invention is capable of correcting superbly spherical aberration upon focusing on a closely distant object in the telephoto end state and eccentric coma aberration upon conducting the vibration reduction.

[0203] When the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the third embodiment of the present application is equal to or exceeds the upper limit, refractive power of the third lens group becomes large, and it becomes difficult to correct spherical aberration upon focusing on the closely distant object in the telephoto end state. It is not preferable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (3) to 1.00.

[0204] On the other hand, when the value of $(-f_{VR})/f_3$ of the conditional expression (3) of the variable magnification optical system according to the third embodiment of the present application is equal to or falls below the lower limit, refractive power of the vibration reduction lens group increases. Thus, eccentric coma aberration is generated upon conducting the vibration reduction, so that it is not desirable. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (3) to 0.40.

[0205] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the second lens group is moved in the direction of the optical axis. With taking such a configuration, curvature of field can be corrected superbly.

[0206] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the third lens group is moved in the direction of the optical axis. With taking such a configuration, spherical aberration can be corrected superbly.

[0207] Further, in the variable magnification optical system according to the third embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, the first lens group is moved in the direction of the optical axis. With taking such a configuration, higher zoom ratio can be attained.

[0208] The optical apparatus of the present application, is characterized in the provision of the variable magnification optical system according to the third embodiment having the above described configuration. Owing to this, an optical apparatus having high zoom ratio, being downsized and having superb optical performance, can be realized.

[0209] The method for manufacturing the variable magnification optical system according to the third embodiment of the present application is a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group, and being characterized in comprising the steps of: [0210] constructing such that the third lens group is composed of a cemented lens constructed by a positive lens cemented with a negative lens; [0211] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group is moved

toward the object side; and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group are varied; [0212] constructing such that upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis.

[0213] By such a method, it is possible to manufacture a variable magnification optical system that has high zoom ratio, is downsized and has superb optical performance.

[0214] The variable magnification optical system, the optical apparatus and the method for manufacturing the variable magnification optical system according to the fourth embodiment of the present application is explained below.

[0215] The variable magnification optical system according to the fourth embodiment of the present application comprises, 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 fourth lens group having positive refractive power; [0216] upon zooming from a wide-angle end state to a telephoto end state, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the fourth lens group are varied.

By such a configuration, the variable magnification optical system according to the fourth embodiment of the present application can realize zooming from a wide-angle end state to a telephoto end state, and variation in distortion caused upon zooming can be suppressed.

[0217] Further, the variable magnification optical system according to the fourth embodiment of the present application is characterized in having at least one lens that satisfies the following conditional expressions (7) and (8):

$$[00019] \quad 1.928 < n_{dh} \quad (7) \quad 28.6 < v_{dh} \quad (8)$$

where n_{dh} denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the lens, and v_{dh} denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the lens.

[0218] The conditional expression (7) defines optimal refractive index of the lens. With satisfying the conditional expression (7), the variable magnification optical system according to the fourth embodiment of the present application is capable of suppressing variation in spherical aberration as well as variation in astigmatism upon zooming, while being downsized.

[0219] When the value of n_{dh} of the conditional expression (7) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in spherical aberration as well as variation in astigmatism upon zooming, so that high optical performance cannot become realized. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (7) to 1.940.

[0220] In order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (7) to 2.800. If the value of n_{dh} is made smaller than 2.800, it is possible to ensure sufficiently transmittance of visible light rays for material of the lens.

[0221] The conditional expression (8) defines optimal Abbe number of the lens. With satisfying the conditional expression (8), the variable magnification optical system according to the fourth embodiment of the present application is capable of suppressing variation in longitudinal chromatic aberration as well as variation in lateral chromatic aberration upon zooming, while being downsized.

[0222] When the value of v_{dh} of the conditional expression (8) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in longitudinal chromatic aberration as well as variation in lateral chromatic aberration upon zooming, so that high optical

performance cannot become realized. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (8) to 29.00. In order to attain the advantageous effect of the present application further more surely, it is further more preferable to set the lower limit value of the conditional expression (8) to 32.00.

[0223] In order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (8) to 50.00. If the value of v_{dh} is made smaller than 50.00, it is possible to suppress variation in longitudinal chromatic aberration and variation in lateral chromatic aberration which are generated at other lenses than the said lens upon zooming, and accordingly high optical performance can be realized.

[0224] Due to the above described configuration, a variable magnification optical system that is downsized and has high optical performance, can be realized.

[0225] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the first lens group has at least one said lens. By such configuration, it is possible to suppress respective variations in spherical aberration, astigmatism, longitudinal chromatic aberration and lateral chromatic aberration which are generated at the first lens group upon zooming.

[0226] Further, in the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the following conditional expression (9) is satisfied:

$$[00020] \quad 5.5 < f_1 / (-f_2) < 15. \quad (9)$$

where f_1 denotes a focal length of the first lens group, and f_2 denotes a focal length of the second lens group.

[0227] The conditional expression (9) defines the focal length of the first lens group relative to the focal length of the second lens group. With satisfying the conditional expression (9), the variable magnification optical system according to the fourth embodiment of the present invention is capable of suppressing variation in astigmatism upon zooming while maintaining high zoom ratio.

[0228] When the value of $f_1/(-f_2)$ of the conditional expression (9) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, astigmatism is generated largely in the wide-angle end state, so that it becomes not possible to attain high optical performance. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the lower limit value of the conditional expression (9) to 5.90.

[0229] On the other hand, when the value of $f_1/(-f_2)$ of the conditional expression (9) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or exceeds the upper limit, it becomes difficult to suppress variation in astigmatism generated at the second lens group upon zooming. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (9) to 11.50. Further, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (9) to 10.20. Due to the above described configuration, a variable magnification optical system that is downsized and has high optical performance, can be realized.

[0230] Further, in the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the following conditional expression (10) is satisfied:

$$[00021] \quad 0.22 < (-f_2) / f_3 < 0.53 \quad (10)$$

where f_2 denotes the focal length of the second lens group, and f_3 denotes a focal length of the third lens group.

[0231] The conditional expression (10) defines a proper range of a ratio of the focal length of the second lens group to the focal length of the third lens group. The variable magnification optical system according to the fourth embodiment of the present invention is capable of suppressing

variation in spherical aberration and variation in astigmatism upon zooming, while maintaining high zoom ratio, by satisfying the conditional expression (10).

[0232] When the value of $(-f_2)/f_3$ of the conditional expression (10) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in astigmatism generated at the second lens group upon zooming. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (10) to 0.270.

[0233] On the other hand, when the value of $(-f_2)/f_3$ of the conditional expression (10) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or exceeds the upper limit, it becomes difficult to suppress variation in spherical aberration generated at the third lens group upon zooming. Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the upper limit value of the conditional expression (10) to 0.490. Furthermore, it is more preferable to set the upper limit value of the conditional expression (10) to 0.450.

[0234] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the first lens group has at least one lens that satisfies the following conditional expression (11):

$$[00022] \ 0.45 < f_h / f_1 < 1.4 \quad (11)$$

where f_h denotes a focal length of the lens in the first lens group, and f_1 denotes the focal length of the first lens group.

[0235] The conditional expression (11) defines a proper focal length range of the said lens in the first lens group. Meanwhile, when the said lens is cemented with other lens, f_h denotes the focal length of the said lens alone. In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the first lens group has at least one said lens. The variable magnification optical system according to the fourth embodiment of the present application can suppress respective variations in spherical aberration, astigmatism, longitudinal chromatic aberration and lateral chromatic aberration which are generated upon zooming, by satisfying the conditional expression (11).

[0236] Here, with respect to the conditional expression (11), two cases where the said lens has positive refractive power and where the said lens has negative refractive power will be separately explained.

[0237] In the case where the said lens has positive refractive power, when the value of $|f_h/f_1|$ of the conditional expression (11) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in longitudinal chromatic aberration and variation in lateral chromatic aberration generated at the said lens upon zooming, so that high optical performance can not be realized. On the other hand, when the value of $|f_h/f_1|$ of the conditional expression (11) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or exceeds the upper limit, it becomes difficult to suppress positive spherical aberration generated at the second lens group in the telephoto end state, thereby it becoming not possible to realize high optical performance.

[0238] In the case where the said lens has negative refractive power, when the value of $|f_h/f_1|$ of the conditional expression (11) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in astigmatism generated at the said lens upon zooming, so that high optical performance can not be realized. On the other hand, when the value of $|f_h/f_1|$ of the conditional expression (11) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or exceeds the upper limit, it becomes difficult to suppress

variation in longitudinal chromatic aberration and variation in lateral chromatic aberration which are generated at other lenses than the said lens upon zooming, and accordingly high optical performance can not be realized.

[0239] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is more preferable to set the lower limit value of the conditional expression (11) to 0.620. Further, it is more preferable to set the upper limit value of the conditional expression (11) to 1.290.

[0240] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the fourth lens group has at least one said lens. With this configuration, it is possible to suppress, from the wide-angle end state to the telephoto end state, respective variations in spherical aberration, astigmatism, longitudinal chromatic aberration and lateral chromatic aberration which are generated at the fourth lens group.

[0241] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the second lens group has at least one said lens. With this configuration, it is possible to suppress, from the wide-angle end state to the telephoto end state, respective variations in spherical aberration, astigmatism, longitudinal chromatic aberration and lateral chromatic aberration which are generated at the second lens group upon zooming.

[0242] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the third lens group has at least one said lens. With this configuration, it is possible to suppress, from the wide-angle end state to the telephoto end state, respective variations in spherical aberration, astigmatism, longitudinal chromatic aberration and lateral chromatic aberration which are generated at the third lens group upon zooming.

[0243] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the first lens group has at least one said lens that has negative refractive power. With this configuration, it is possible to suppress variation in astigmatism, variation in spherical aberration, longitudinal chromatic aberration and particularly variation in secondary chromatic aberration, which are generated at the first lens group upon zooming, thereby it becoming possible to realize high optical performance.

[0244] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the fourth lens group has at least one said lens that has negative refractive power. With this configuration, it is possible to suppress variation in astigmatism, variation in spherical aberration and longitudinal chromatic aberration which are generated at the fourth lens group upon zooming, thereby it becoming possible to realize high optical performance.

[0245] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the fourth lens group has at least one said lens that satisfies the following conditional expression (12):

$$[00023] \quad 31.6 < v_{dh4} \quad (12)$$

Where v_{dh4} denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the said lens in the fourth lens group.

[0246] The conditional expression (12) defines optimal Abbe number of the said lens in the fourth lens group. With satisfying the conditional expression (12), the variable magnification optical system according to the fourth embodiment of the present invention is capable of suppressing longitudinal chromatic aberration and lateral chromatic aberration.

[0247] When the value of v_{dh4} of the conditional expression (12) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress longitudinal chromatic aberration and lateral chromatic aberration generated at other lenses than the said lens, so that high optical performance can not be realized.

[0248] In the variable magnification optical system according to the fourth embodiment of the

present application, it is preferable that the second lens group has at least one said lens that has negative refractive power. With this configuration, it is possible to suppress variation in longitudinal chromatic aberration, lateral chromatic aberration and particularly secondary chromatic aberration, which are generated at the second lens group, thereby it becoming possible to realize high optical performance.

[0249] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the third lens group has at least one said lens, has negative refractive power. With this configuration, it is possible to suppress longitudinal chromatic aberration and particularly secondary chromatic aberration, which are generated at the third lens group, thereby it becoming possible to realize high optical performance.

[0250] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the first lens group has at least one positive lens that satisfies the following conditional expression (13):

$$[00024] \quad 75. < vdp1 \quad (13)$$

Where vdp1 denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the said positive lens in the first lens group.

[0251] The conditional expression (13) defines optimal Abbe number of the said positive lens in the first lens group. With satisfying the conditional expression (13), the variable magnification optical system according to the fourth embodiment of the present invention is capable of suppressing variation in longitudinal chromatic aberration and variation in lateral chromatic aberration, upon zooming.

[0252] When the value of vdp1 of the conditional expression (13) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in longitudinal chromatic aberration and variation in lateral chromatic aberration, upon zooming, so that high optical performance can not be realized.

[0253] Meanwhile, in order to attain the advantageous effect of the present application more surely, it is preferable to set the upper limit value of the conditional expression (13) to 99.00. If the value of vdp1 in the conditional expression (13) of the variable magnification optical system according to the fourth embodiment of the present application, is smaller than 99.00, it is possible to suppress variation in longitudinal chromatic aberration and variation in lateral chromatic aberration which are generated at other lenses than the said positive lens upon zooming, so that high optical performance can be realized.

[0254] In the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that the fourth lens group has a positive lens that satisfies the following conditional expression (14):

$$[00025] \quad 75. < vdp4 \quad (14)$$

Where vdp4 denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the said positive lens in the fourth lens group.

[0255] The conditional expression (14) defines optimal Abbe number of the said positive lens in the fourth lens group. With satisfying the conditional expression (14), the variable magnification optical system according to the fourth embodiment of the present invention is capable of suppressing variation in longitudinal chromatic aberration and variation in lateral chromatic aberration, upon zooming.

[0256] When the value of vdp4 of the conditional expression (14) of the variable magnification optical system according to the fourth embodiment of the present application is equal to or falls below the lower limit, it becomes difficult to suppress variation in longitudinal chromatic aberration, upon zooming, so that high optical performance can not be realized.

[0257] Meanwhile, in order to attain the advantageous effect of the present application more surely,

it is preferable to set the upper limit value of the conditional expression (14) to 99.00. If the value of $vdp4$ in the conditional expression (14) of the variable magnification optical system according to the fourth embodiment of the present application, is smaller than 99.00, it is possible to suppress variation in longitudinal chromatic aberration generated at other lenses than the said positive lens, so that high optical performance can be realized.

[0258] Further, in the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, a distance between the first lens group and the second lens group increases. With such configuration, the focal length of the first lens group and the focal length of the second lens group can be made proper. And, spherical aberration and astigmatism generated at each lens can be suppressed, and variation in spherical aberration and variation in astigmatism upon zooming can be suppressed.

[0259] Further, in the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, a distance between the second lens group and the third lens group decreases. With such configuration, the focal length of the second lens group and the focal length of the third lens group can be made proper. And, spherical aberration and astigmatism generated at each lens can be suppressed, and variation in spherical aberration and variation in astigmatism upon zooming can be suppressed.

[0260] Further, in the variable magnification optical system according to the fourth embodiment of the present application, it is preferable that, upon zooming from the wide-angle end state to the telephoto end state, a distance between the third lens group and the fourth lens group increases. With such configuration, variation in spherical aberration and variation in astigmatism generated at the third lens group and the fourth lens group upon zooming can be suppressed.

[0261] The optical apparatus of the present application, is characterized in the provision of the variable magnification optical system according to the fourth embodiment having the above described configuration. Owing to this, an optical apparatus that is downsized and has high optical performance, can be realized.

[0262] The method for manufacturing the variable magnification optical system according to the fourth embodiment of the present application is a method for manufacturing 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 fourth lens group having positive refractive power, and being characterized in comprising the steps of: [0263] constructing such that at least one lens satisfies the following conditional expressions (7) and (8):

$$[00026] \quad 1.928 < ndh \quad (7) \quad 28.6 < vdh \quad (8)$$

where ndh denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the said lens, and vdh denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the said lens; and [0264] constructing such that, upon zooming from a wide-angle end state to a telephoto end state, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the fourth lens group are varied. By such a configuration, it is possible to manufacture a variable magnification optical system that is downsized and has high optical performance.

[0265] Hereinafter, a variable magnification optical system relating to numerical examples according to the first to the third embodiments of the present application will be explained with reference to the accompanying drawings. Meanwhile, the first to the third examples are common to all of the first to the third embodiments.

First Example

[0266] FIGS. 1A, 1B and 1C are sectional views showing a variable magnification optical system

according to a first example that is common to a first to third embodiments of the present application, in which FIG. 1A shows sectional view in a wide-angle end state, FIG. 1B shows sectional view in an intermediate focal length state, and FIG. 1C shows sectional view in a telephoto end state.

[0267] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a rear lens group GR having positive refractive power. The rear lens group GR is composed of, in order from an object side: a fourth lens group G4 having negative refractive power and a fifth lens group G5 having positive refractive power.

[0268] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a convex surface facing the object side.

[0269] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a double concave negative lens L22, a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. The most object side negative meniscus lens L21 in the second lens group G2 is an aspherical lens whose object side lens surface is aspherically shaped.

[0270] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0271] The fourth lens group G4 consists of, in order from the object side, a first segment lens group G41 having positive refractive power and a second segment lens group G42 having negative refractive power.

[0272] The first segment lens group G41 consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L41 cemented with a negative meniscus lens L42 having a concave surface facing the object side.

[0273] The second segment lens group G42 consists of, in order from the object side, a cemented lens constructed by a double concave negative lens L43 cemented with a positive meniscus lens L44 having a convex surface facing the object side. The most object side negative lens L43 in the second segment lens group G42 is an aspherical lens whose object side surface is aspherically shaped.

[0274] The fifth lens group G5 consists of, in order from the object side, a double convex positive lens L51, and a cemented lens constructed by a double convex positive lens L52 cemented with a negative meniscus lens L53 having a concave surface facing the object side. The most object side positive lens L51 in the fifth lens group G5 is an aspherical lens whose object side surface is aspherically shaped.

[0275] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1, the third lens group G3, the fourth lens group G4 and the fifth lens group G5 along the optical axis toward the object side and moving the second lens group G2 and the aperture stop S along the optical axis such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is varied, and a distance between the fourth lens group G4 and the fifth lens group G5 is decreased.

[0276] In the variable magnification optical system according to the present example, the third group G3 as a whole is moved along the optical axis toward the image side, thereby conducting focusing from an infinitely distant object to a close distant object.

[0277] In the variable magnification optical system according to the present example, only the second segment lens group G42 in the fourth lens group G4 is moved, as a vibration reduction lens group, to have a component in a direction perpendicular to the optical axis, thereby conducting vibration reduction.

[0278] It is noted that in a lens system having a focal length f of the whole lens system and a vibration reduction coefficient K , which is a ratio of a moving amount of an image on the image plane I to a moving amount of the vibration reduction lens group upon conducting a vibration reduction, it is possible to correct rotational camera shake of an angle θ , by moving the vibration reduction lens group by the amount of $(f \cdot \tan \theta) / K$ perpendicularly to the optical axis.

[0279] Accordingly, in the variable magnification optical system according to the present example, in the wide-angle end state, the vibration reduction coefficient K is -1.03 , and the focal length is 10.30 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.62 degrees is -0.11 (mm). In the telephoto end state, the vibration reduction coefficient K is -1.87 , and the focal length is 97.00 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.20 degrees is -0.18 (mm).

[0280] Table 1 below shows various values of the variable magnification optical system according to the present example.

[0281] In table 1, f denotes a focal length, and BF denotes a back focal length (a distance on the optical axis between the most image side lens surface and the image plane I).

[0282] In [Surface Data], m denotes an order of an optical surface counted from the object side, r denotes a radius of curvature, d denotes a surface-to-surface distance (an interval from an n -th surface to an $(n+1)$ -th surface, where n is an integer.), n_d denotes refractive index for d-line (wavelength $\lambda=587.6$ nm) and v_d denotes an Abbe number for d-line (wavelength $\lambda=587.6$ nm). Further, OP denotes an object surface, and I denotes an image plane. Meanwhile, radius of curvature $r=\infty$ denotes a plane surface. The position of an aspherical surface is expressed by attaching “*” to the surface number, and in the column of the radius of curvature, a paraxial radius of curvature is shown.

[0283] In [Aspherical Data], with respect to an aspherical surface shown in [Surface Data], an aspherical surface coefficient and a conical coefficient are shown in the case where the aspherical surface is exhibited by the following expression:

$$[00027] X = (h^2 / r) / [1 + [1 - K(h^2 / r^2)]^{1/2}] + A4h^4 + A6h^6 + A8h^8 + A10h^{10}$$

where h denotes a vertical height from the optical axis, X denotes a sag amount which is a distance along the optical axis from the tangent surface at the vertex of the aspherical surface to the aspherical surface at the vertical height from the optical axis, K denotes a conical coefficient, $A4$, $A6$, $A8$ and $A10$ denote respective aspherical coefficients, and r denotes a paraxial radius of curvature that is a radius of curvature of a reference sphere. “E- n ”, where n is an integer, denotes “ $\times 10.\text{sup.}-n$ ”, for example, “ $1.234\text{E}-05$ ” denotes “ $1.234 \times 10.\text{sup.}-5$ ”. The 2nd order aspherical surface coefficient $A2$ is 0, and omitted in the description.

[0284] In [Various Data], FNO denotes an f-number, 2ω denotes an angle of view (unit “°”, Y denotes an image height, TL denotes a total length of the variable magnification optical system, that is, a distance along the optical axis from the first surface to the image plane I, d_n denotes a variable interval between an n -th surface and an $(n+1)$ -th surface. B denotes a phototaking magnification upon focusing on an object of 0.45 mm. Meanwhile, W denotes a wide-angle end state, M denotes an intermediate focal length state, and T denotes a telephoto end state.

[0285] In [Lens Group Data], a starting surface ST and focal length of each lens group are shown.

[0286] In [Values for Conditional Expressions], values corresponding to respective conditional expressions are shown.

[0287] It is noted, here, that “mm” is generally used for the unit of length such as the focal length f , the radius of curvature r and the unit for other lengths shown in Table 1. However, since similar

optical performance can be obtained by an optical system proportionally enlarged or reduced its dimension, the unit is not necessarily to be limited to “mm”.

[0288] The explanation of reference symbols in Table 1 described above, is the same in Tables for the other examples.

TABLE-US-00001 TABLE 1 First Example [Surface Data] m r d nd vd OP ∞ 1 149.869 1.600 1.94967 27.56 2 44.374 6.840 1.49782 82.51 3 -243.506 0.100 1.00000 4 45.376 5.351 1.86790 41.78 5 311.414 d5 1.00000 *6 89.024 1.200 1.83481 42.73 7 8.490 3.758 1.00000 8 -15.726 1.000 1.83481 42.73 9 250.000 0.100 1.00000 10 25.275 3.293 1.80809 22.74 11 -17.475 0.548 1.00000 12 -12.620 1.000 1.81600 46.59 13 -33.425 d13 1.00000 14 ∞ d14 1.00000 Aperture Stop S 15 29.168 1.000 1.88904 39.77 16 18.240 3.207 1.59313 66.16 17 -26.526 d17 1.00000 18 14.286 3.565 1.49782 82.51 19 -21.978 1.000 1.90200 25.23 20 -82.840 2.205 1.00000 *21 -52.307 1.000 1.84898 43.01 22 9.141 2.692 1.95000 29.37 23 25.864 d23 1.00000 *24 35.441 3.335 1.58913 61.22 25 -21.319 0.300 1.00000 26 42.310 4.403 1.58144 40.98 27 -10.198 1.200 1.95400 33.46 28 -300.472 BF 1.00000 I ∞ [Aspherical Surface Data] m κ A4 A6 A8 A10 6 1.00000 3.46E-05 -1.39E-07 -5.60E-11 1.26E-11 21 1.00000 1.74E-06 1.28E-07 -2.64E-09 24 1.00000 -1.23E-05 1.47E-07 -5.49E-10 [Various Data] zoom ratio 9.42 W M T f 10.30 50.00 97.00 FNO 3.50 5.20 5.60 2 ω 79.80 18.04 9.37 Y 8.19 8.19 8.19 TL 99.26 129.21 139.68 [Upon focusing an infinitely distant object] W M T f 10.30 50.00 97.00 d5 2.000 30.682 41.260 d13 18.534 4.142 2.000 d14 3.765 2.963 1.400 d17 3.542 4.343 5.907 d23 8.018 3.307 3.300 BF 14.70 35.08 37.11 [Upon focusing on a closely distant object] W M T β -0.025 -0.103 -0.153 d5 2.000 30.682 41.260 d13 18.534 4.142 2.000 d14 4.216 4.444 5.211 d17 3.090 2.863 2.096 d23 8.018 3.307 3.300 BF 14.70 35.08 37.11 [Lens Group Data] ST f G1 1 66.85 G2 6 -9.36 G3 15 27.88 G4 18 -160.92 G5 24 33.56 GR 18 53.0 [Values for Conditional Expression] (1) $f_1/f_3 = 2.40$ (2) $f_1/(-f_2) = 7.14$ (3) $(-f_{VR})/f_3 = 0.85$ (4) $(-f_2)/f_3 = 0.34$ (5) $f_3/f_R = 0.53$ (6) $nd_1 = 1.94967$

[0289] FIGS. 2A, 2B and 2C are graphs showing various aberrations of the variable magnification optical system according to the first example of the present application upon focusing on an infinitely distant object, in which FIG. 2A is in a wide-angle end state, FIG. 2B is in an intermediate focal length state, and FIG. 2C is in a telephoto end state.

[0290] FIGS. 3A and 3B are graphs showing meridional transverse aberration of the variable magnification optical system according to the first example upon focusing on an infinitely distant object in the wide-angle end state with carrying out vibration reduction in which FIG. 3A is for a rotational camera shake of 0.62 degrees in the wide-angle end state, and FIG. 3B is for a rotational camera shake of 0.20 degrees in a telephoto end state.

[0291] In respective graphs, FNO denotes an f-number, Y denotes an image height. In respective graphs, d denotes an aberration curve at d-line (wavelength $\lambda=587.6$ nm), and g denotes an aberration curve at g-line (wavelength $\lambda=435.8$ nm). In the graph showing astigmatism, a solid line indicates a sagittal image plane, and a broken line indicates a meridional image plane.

[0292] Incidentally, the above-described explanation regarding various aberration graphs is the same as the other Examples.

[0293] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state, and also shows superb optical performance upon carrying out vibration reduction.

Second Example

[0294] FIGS. 4A, 4B and 4C are sectional views showing a variable magnification optical system according to a second example that is common to the first to third embodiments of the present application, in which FIG. 4A shows sectional view in a wide-angle end state, FIG. 4B shows sectional view in an intermediate focal length state, and FIG. 4C shows sectional view in a telephoto end state.

[0295] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a rear lens group GR having positive refractive power. The rear lens group GR is composed of, in order from an object side: a fourth lens group G4 having negative refractive power and a fifth lens group G5 having positive refractive power.

[0296] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a convex surface facing the object side.

[0297] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a double concave negative lens L22, a cemented lens constructed by a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. The most object side negative meniscus lens L21 in the second lens group G2 is an aspherical lens whose object side lens surface is aspherically shaped.

[0298] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0299] The fourth lens group G4 consists of, in order from the object side, a first segment lens group G41 having positive refractive power and a second segment lens group G42 having negative refractive power.

[0300] The first segment lens group G41 consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L41 cemented with a negative meniscus lens L42 having a concave surface facing the object side.

[0301] The second segment lens group G42 consists of, in order from the object side, a cemented lens constructed by a double concave negative lens L43 cemented with a double convex positive lens L44. The most object side negative lens L43 in the second segment lens group G42 is an aspherical lens whose object side surface is aspherically shaped.

[0302] The fifth lens group G5 consists of, in order from the object side, a double convex positive lens L51, a cemented lens constructed by a double convex positive lens L52 cemented with a negative meniscus lens L53 having a concave surface facing the object side. The most object side positive lens L51 in the fifth lens group G5 is an aspherical lens whose object side surface is aspherically shaped.

[0303] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1, the third lens group G3, the fourth lens group G4 and the fifth lens group G5 along the optical axis toward the object side and moving the second lens group G2 and the aperture stop S along the optical axis such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is varied, and a distance between the fourth lens group G4 and the fifth lens group G5 is decreased.

[0304] In the variable magnification optical system according to the present example, the third group G3 as a whole is moved along the optical axis toward the image side, thereby conducting focusing from an infinitely distant object to a close distant object.

[0305] In the variable magnification optical system according to the present example, only the second segment lens group G42 in the fourth lens group G4 is moved, as a vibration reduction lens group, to have a component in a direction perpendicular to the optical axis, thereby conducting vibration reduction.

[0306] In the variable magnification optical system according to the present example, in the wide-angle end state, the vibration reduction coefficient is -1.43 , and the focal length is 10.30 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.62 degrees is -0.08 (mm). In the telephoto end state, the vibration reduction coefficient is -2.59 , and the focal length is 97.00 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.20 degrees is -0.13 (mm).

TABLE-US-00002 TABLE 2 Second Example [Surface Data] m r d nd vd OP ∞ 1 161.271 1.600 1.95000 29.37 2 49.424 6.736 1.49782 82.51 3 -163.134 0.100 1.00000 4 42.661 5.130 1.80400 46.60 5 174.429 d5 1.00000 *6 81.138 1.200 1.81600 46.59 7 8.430 3.674 1.00000 8 -20.479 1.000 1.88300 40.76 9 120.000 0.100 1.00000 10 20.642 3.336 1.80809 22.74 11 -21.855 1.000 1.83481 42.73 12 -2443.660 d12 1.00000 13 ∞ d13 1.00000 Aperture Stop S 14 32.818 1.000 1.95400 33.46 15 12.652 3.417 1.75484 52.35 16 -38.178 d16 1.00000 17 14.363 4.402 1.49782 82.51 18 -19.407 1.000 1.88087 27.51 19 -31.773 2.035 1.00000 *20 -36.627 1.000 1.88300 40.66 21 7.873 2.750 1.95000 29.37 22 20.460 d22 1.00000 *23 34.272 3.115 1.61800 63.34 24 -25.939 0.100 1.00000 25 29.742 4.552 1.58144 40.98 26 -10.558 1.200 1.95400 33.46 27 -228.600 BF 1.00000 I ∞ [Aspherical Surface Data] m κ A4 A6 A8 6 1.00000 $-2.03E-06$ $2.60E-08$ $-4.85E-10$ 20 1.00000 $2.72E-05$ $-6.63E-08$ 23 1.00000 $-9.13E-06$ $3.14E-08$ [Various Data] zoom ratio 9.42 W M T f 10.30 50.00 97.00 FNO 3.50 5.20 5.60 2ω 79.80 18.04 9.37 Y 8.19 8.19 8.19 TL 98.69 127.23 138.71 [Upon focusing an infinitely distant object] W M T f 10.30 50.00 97.00 d5 2.000 30.607 41.889 d12 18.865 3.375 2.000 d13 5.283 4.127 1.400 d16 2.502 3.658 6.385 d22 7.241 3.302 3.300 BF 14.35 33.71 35.29 [Upon focusing on a closely distant object] W M T β -0.025 -0.103 -0.152 d5 2.000 30.607 41.889 d12 18.865 3.375 2.000 d13 5.785 5.785 5.774 d16 2.000 2.000 2.011 d22 7.241 3.302 3.300 BF 14.35 33.71 35.29 [Lens Group Data] ST f G1 1 69.02 G2 6 -10.07 G3 14 30.75 G4 17 -167.27 G5 23 28.42 GR 17 46.2 [Values for Conditional Expression] (1) $f1/f3 = 2.24$ (2) $f1/(-f2) = 6.85$ (3) $(-fVR)/f3 = 0.51$ (4) $(-f2)/f3 = 0.33$ (5) $f3/fR = 0.67$ (6) $nd1 = 1.95000$

[0307] FIGS. 5A, 5B and 5C are graphs showing various aberrations of the variable magnification optical system according to the second example of the present application upon focusing on an infinitely distant object, in which FIG. 5A is in a wide-angle end state, FIG. 5B is in an intermediate focal length state, and FIG. 5C is in a telephoto end state.

[0308] FIGS. 6A and 6B are graphs showing meridional transverse aberration of the variable magnification optical system according to the second example upon focusing on an infinitely distant object in the wide-angle end state with carrying out vibration reduction in which FIG. 6A is for a rotational camera shake of 0.62 degrees in the wide-angle end state, and FIG. 6B is for a rotational camera shake of 0.20 degrees in a telephoto end state.

[0309] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state, and also shows superb optical performance upon carrying out vibration reduction.

Third Example

[0310] FIGS. 7A, 7B and 7C are sectional views showing a variable magnification optical system according to a third example that is common to the first to third embodiments of the present application, in which FIG. 7A shows sectional view in a wide-angle end state, FIG. 7B shows sectional view in an intermediate focal length state, and FIG. 7C shows sectional view in a telephoto end state.

[0311] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a rear lens group GR having positive refractive power. The rear lens group GR consists of a fourth lens group G4 having positive refractive power.

[0312] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a plano-convex positive lens L13 having a convex surface facing the object side.

[0313] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a negative meniscus lens L22 having a concave surface facing the object side, a cemented lens constructed by a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. The most object side negative meniscus lens L21 in the second lens group G2 is an aspherical lens whose object side lens surface is provided with a resin layer to be formed with an aspherical surface. The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0314] The fourth lens group G4 consists of, in order from the object side, a first segment lens group G41 having positive refractive power, a second segment lens group G42 having negative refractive power and a third segment lens group G43 having positive refractive power.

[0315] The first segment lens group G41 consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a negative meniscus lens L402 having a concave surface facing the object side.

[0316] The second segment lens group G42 consists of, in order from the object side, a cemented lens constructed by a positive meniscus lens L403 cemented with a double concave negative lens L404. The most image side negative lens L404 in the second segment lens group G42 is an aspherical lens whose image side surface is aspherically shaped.

[0317] The third segment lens group G43 consists of, in order from the object side, a double convex positive lens 405, a cemented lens constructed by a double convex positive lens L406 cemented with a double concave negative lens L407, a cemented lens constructed by a double convex positive lens L408 cemented with a negative meniscus lens L409 having a concave surface facing the object side, and a negative meniscus lens having a concave surface facing the object side. The most image side negative lens L410 in the third segment lens group G43 is an aspherical lens whose image side surface is aspherically shaped.

[0318] By the above described configuration, in the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1, the third lens group G3 and the fourth lens group G4 along the optical axis toward the object side and moving the second lens group G2 and the aperture stop S along the optical axis such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, and a distance between the third lens group G3 and the fourth lens group G4 is varied.

[0319] In the variable magnification optical system according to the present example, the third group G3 as a whole is moved along the optical axis toward the image side, thereby conducting focusing from an infinitely distant object to a close distant object.

[0320] In the variable magnification optical system according to the present example, only the second segment lens group G42 in the fourth lens group G4 is moved, as a vibration reduction lens group, to have a component in a direction perpendicular to the optical axis, thereby conducting vibration reduction.

[0321] In the variable magnification optical system according to the present example, in the wide-angle end state, the vibration reduction coefficient is -0.92 , and the focal length is 10.30 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.62 degrees is -0.12 (mm). In the telephoto end state, the vibration reduction coefficient

is -1.68 , and the focal length is 97.00 (mm), so that the moving amount of the second segment lens group G42 for correcting a rotational camera shake of 0.20 degrees is -0.20 (mm). Table 3 below shows various values of the variable magnification of the present example.

TABLE-US-00003 TABLE 3 Third Example [Surface Data] m r d nd vd OP ∞ 1 145.183 1.700 2.00100 29.14 2 36.639 8.100 1.49782 82.57 3 -399.352 0.100 1.00000 4 43.208 6.000 1.88300 40.66 5 ∞ d5 1.00000 *6 436.597 0.100 1.55389 38.09 7 87.003 1.100 1.83481 42.73 8 8.300 5.350 1.00000 9 -12.607 1.000 1.75500 52.34 10 -32.799 0.800 1.00000 11 41.120 2.950 1.80809 22.74 12 -19.604 0.900 1.88300 40.66 13 -73.132 d13 1.00000 14 ∞ d14 1.00000 Aperture Stop S 15 22.373 0.900 1.90265 35.73 16 12.230 3.450 1.67003 47.14 17 -59.699 d17 1.00000 18 13.739 3.600 1.49782 82.57 19 -24.820 0.900 2.00069 25.46 20 -270.014 2.200 1.00000 21 -117.055 2.050 1.84666 23.80 22 -15.985 1.000 1.77377 47.25 *23 24.175 2.084 1.00000 24 66.365 2.800 1.56883 56.00 25 -15.447 0.100 1.00000 26 44.994 2.750 1.51742 52.20 27 -15.201 0.900 1.90366 31.27 28 29.993 0.300 1.00000 29 14.609 5.050 1.67270 32.19 30 -9.200 0.900 2.00069 25.46 31 -24.389 1.400 1.00000 32 -12.862 1.000 1.85135 40.10 *33 -27.495 BF 1.00000 I ∞ [Aspherical Surface Data] m κ A4 A6 A8 A10 6 20.00000 9.17E-05 $-6.52E-07$ 2.70E-09 $-1.24E-11$ 23 0.48230 $-7.25E-06$ $-3.60E-07$ 4.06E-09 33 -20.00000 $-1.23E-04$ 8.28E-07 $-6.05E-09$ $-9.89E-11$ [Various Data] zoom ratio 9.42 W M T f 10.30 30.00 96.99 FNO 4.12 5.48 5.80 2ω 80.89 29.72 9.45 Y 8.19 8.19 8.19 TL 103.03 121.38 143.32 [Upon focusing an infinitely distant object] W M T f 10.30 30.00 96.99 d5 2.106 20.131 40.209 d13 19.664 6.244 1.800 d14 4.279 4.974 1.800 d17 3.438 2.743 5.916 BF 14.06 27.81 34.12 [Upon focusing on a closely distant object] W M T β -0.032 -0.068 -0.116 d5 2.106 20.131 40.209 d13 19.664 6.244 1.800 d14 4.983 5.899 5.217 d17 2.733 1.818 2.499 BF 14.06 27.81 34.12 [Lens Group Data] ST f G1 1 64.10 G2 6 -10.17 G3 15 31.06 G4(R) 18 67.06 [Values for Conditional Expression] (1) $f1/f3 = 2.06$ (2) $f1/(-f2) = 6.30$ (3) $(-fVR)/f3 = 0.92$ (4) $(-f2)/f3 = 0.33$ (5) $f3/fR = 0.46$ (6) $nd1 = 2.00100$

[0322] FIGS. 8A, 8B and 8C are graphs showing various aberrations of the variable magnification optical system according to the third example of the present application upon focusing on an infinitely distant object, in which FIG. 8A is in a wide-angle end state, FIG. 8B is in an intermediate focal length state, and FIG. 8C is in a telephoto end state.

[0323] FIGS. 9A and 9B are graphs showing meridional transverse aberration of the variable magnification optical system according to the third example upon focusing on an infinitely distant object in the wide-angle end state with carrying out vibration reduction in which FIG. 9A is for a rotational camera shake of 0.62 degrees in the wide-angle end state, and FIG. 9B is for a rotational camera shake of 0.20 degrees in a telephoto end state.

[0324] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state, and also shows superb optical performance upon carrying out vibration reduction.

[0325] According to the first to third examples, a variable magnification optical system that has high zoom ratio, is downsized and excellent optical performance can be realized. In particular, the variable magnification optical systems according to the first to third examples each has vibration reducing function and zoom ratio of about 10 and is compact in size and light in weight, and angle of view in the wide-angle end state is more than 70 degrees, and variation in various aberrations upon focusing on a closely distant object can be corrected excellently.

[0326] Hereinafter, a variable magnification optical system relating to numerical examples according to the fourth embodiment of the present application will be explained with reference to the accompanying drawings. Meanwhile, the fourth to the eighth examples are of the fourth embodiment.

Fourth Example

[0327] FIGS. 10A, 10B and 10C are sectional views showing a variable magnification optical

system according to a fourth example of the fourth embodiment of the present application, in which FIG. 10A shows sectional view in a wide-angle end state, FIG. 10B shows sectional view in an intermediate focal length state, and FIG. 10C shows sectional view in a telephoto end state.

[0328] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a fourth lens group GR having positive refractive power.

[0329] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a convex surface facing the object side.

[0330] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a double concave negative lens L22, a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. The most object side negative meniscus lens L21 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0331] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0332] The fourth lens group G4 consists of, in order from the object side, a front group G4F having negative refractive power and a rear group G4R having positive refractive power.

[0333] The front group G4F consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a double concave negative lens L402 and a cemented lens constructed by a double concave negative lens L403 cemented with a positive meniscus lens L404 having a convex surface facing the object side. The negative lens L403 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0334] The rear group G4R consists of, in order from the object side, a double convex positive lens L405, a cemented lens constructed by a double convex positive lens L406 cemented with a negative meniscus lens L407 having a concave surface facing the object side, a cemented lens constructed by a negative meniscus lens L408 having a convex surface facing the object side cemented with a double convex positive lens L409, and a negative meniscus lens L410 having a convex surface having the image side. The negative meniscus lens L410 is a glass mold type aspherical lens whose image side lens surface is aspherically shaped.

[0335] Incidentally, in the variable magnification optical system according to the present example, a low pass filter as well as a glass cover for a sensor can be disposed between the fourth lens group G4 and the image plane.

[0336] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1 to the fourth lens group G4 along the optical axis and moving the aperture stop S in a body with the front group G4F in the fourth lens group G4 such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is increased, and a distance between the aperture stop S and the third lens group G3 is decreased. In more detail, upon zooming, the first lens group G1 and the third lens group G3 are moved toward the object side. The second lens group G2 is moved toward the object side from the wide-angle end state to the intermediate focal length state and toward the image side from the intermediate focal length state to the telephoto end state. In the fourth lens group G4, upon zooming from the wide-angle end state to the telephoto end state, the front group G4F and the rear group G4R are moved toward the object side from the wide-angle end state to the intermediate

1.0000 2.000690 25.46 28 -2198.5412 0.7500 29 412.2295 1.0000 1.954000 33.46 30 12.8823
3.5000 1.755200 27.57 31 -23.7185 1.1500 32 -16.1296 1.0000 1.806100 40.71 *33 -97.3104
BF I ∞ [Aspherical Surface Data] m 6 κ -8.7294 A4 4.64796E-05 A6 -4.09659E-07 A8
2.44519E-09 A10 -9.90503E-12 m 21 κ -1.5760 A4 1.72590E-05 A6 9.45415E-08 A8
-1.00397E-09 A10 0.00000E+00 m 33 κ -19.8082 A4 -1.67719E-05 A6 -2.11776E-07 A8
-4.15932E-10 A10 -1.15008E-11 [Various Data] zoom ratio 9.42 W T f 10.30 ~ 97.00 FNO 4.09
~ 5.81 ω 40.21 ~ 4.76° Y 8.19 ~ 8.19 W M T f 10.30000 50.00013 97.00039 ω 40.21337 9.15519
4.75685 FNO 4.09 5.78 5.81 ϕ 7.68 8.50 9.20 TL 100.29944 130.25093 139.59967 d5 2.10000
28.50000 39.66696 d13 17.38897 3.31447 2.00000 d14 4.87082 3.98262 1.60000 d17 2.59389
3.48209 5.86471 d23 5.29632 3.42829 3.30000 BF 13.94944 33.44346 33.06800 [Lens Group
Data] ST f G1 1 64.38705 G2 6 -9.57903 G3 15 29.91408 G4 18 58.41425(W), 61.26584(M),
61.47193(T) G4F 18 -81.48313 G4R 24 28.77173 [Values for Conditional Expression] (7) ndh =
1.954(L31), 1.950(L402), 1.954(L408) (8) vdh = 33.46(L31), 29.37(L402), 33.46(L408) (9)
f1/(-f2) = 6.72 (10) (-f2)/f3 = 0.320 (12) vdh4 = 33.46(L408) (13) vdp1 = 82.57(L12) (14) vdp4 =
82.57(L401)

[0347] FIGS. 11A, 11B and 11C are graphs showing various aberrations of the variable magnification optical system according to the first example of the present application upon focusing on an infinitely distant object, in which FIG. 11A is in a wide-angle end state, FIG. 11B is in an intermediate focal length state, and FIG. 11C is in a telephoto end state.

[0348] In respective graphs, FNO denotes an f-number, A denotes an incident angle of light rays, that is, a half angle of view (unit “°”). d denotes an aberration curve at d-line (wavelength $\lambda=587.6$ nm), and g denotes an aberration curve at g-line (wavelength $\lambda=435.8$ nm). Curves with no d nor g denote aberrations at d-line. In the graph showing astigmatism, a solid line indicates a sagittal image plane, and a broken line indicates a meridional image plane. Incidentally, the signs regarding various aberration graphs of the present example are the same as the other Examples of the fifth to eighth examples described hereinafter.

[0349] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state.

Fifth Example

[0350] FIGS. 12A, 12B and 12C are sectional views showing a variable magnification optical system according to a fifth example of the fourth embodiment of the present application, in which FIG. 12A shows sectional view in a wide-angle end state, FIG. 12B shows sectional view in an intermediate focal length state, and FIG. 12C shows sectional view in a telephoto end state.

[0351] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a fourth lens group G4.

[0352] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a convex surface facing the object side.

[0353] The second lens group G2 consists of, in order from the object side, a double concave negative lens L21, a double concave negative lens L22, a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side.

[0354] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0355] The fourth lens group G4 consists of, in order from the object side, a front group G4F

having negative refractive power and a rear group G4R having positive refractive power.

[0356] The front group G4F consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a double concave negative lens L402 and a cemented lens constructed by a double concave negative lens L403 cemented with a positive meniscus lens L404 having a convex surface facing the object side. The negative lens L403 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0357] The rear group G4R consists of, in order from the object side, a double convex positive lens L405 and a cemented lens constructed by a positive meniscus lens L406 having a concave surface facing the object side cemented with a negative meniscus lens L407 having a concave surface facing the object side. The positive lens L405 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0358] Incidentally, in the variable magnification optical system according to the present example, a low pass filter as well as a glass cover for a sensor can be disposed between the fourth lens group G4 and the image plane.

[0359] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1 to the fourth lens group G4 along the optical axis and moving the aperture stop S in a body with the front group G4F in the fourth lens group G4 such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is increased, and a distance between the aperture stop S and the third lens group G3 is decreased. In more detail, upon zooming, the first lens group G1 and the third lens group G3 are moved toward the object side. The second lens group G2 is moved toward the object side from the wide-angle end state to the intermediate focal length state and toward the image side from the intermediate focal length state to the telephoto end state. In the fourth lens group G4, upon zooming from the wide-angle end state to the telephoto end state, the front group G4F and the rear group G4R are moved toward the object side such that a distance between the front group G4F and the rear group G4R is decreased.

[0360] Table 5 below shows various values of the variable magnification of the present example.

TABLE-US-00005 TABLE 5 Fifth Example [Surface Data] m r d nd vd OP ∞ 1 251.8446 1.6000 1.950000 29.37 2 36.8495 7.9000 1.497820 82.57 3 -162.8867 0.1000 4 41.6898 5.7500 1.883000 40.66 5 7827.2710 d5 6 -808.8261 1.0000 1.883000 40.66 7 9.5148 3.6000 8 -15.5435 1.0000 1.883000 40.66 9 143.0303 0.1000 10 28.6318 3.0500 1.808090 22.74 11 -13.3111 0.2500 12 -12.1771 1.0000 1.834810 42.73 13 -36.4394 d13 14 ∞ d14 Aperture Stop S 15 27.0772 1.0000 2.000690 25.46 16 15.7705 2.5000 1.744000 44.80 17 -35.2142 d17 18 12.6941 2.9500 1.497820 82.57 19 -24.8876 1.0000 1.846660 23.80 20 775.1758 2.1500 *21 -227.6550 1.0000 1.806100 40.97 22 8.8217 2.2000 1.846660 23.80 23 19.5840 d23 *24 15.0000 3.1500 1.583130 59.42 25 -23.9888 0.1000 26 -509.6518 4.2000 1.581440 40.98 27 -7.8594 1.0000 1.954000 33.46 28 -200.0000 BF I ∞ [Aspherical Surface Data] M 21 κ -20.0000 A4 1.61374E-05 A6 -2.79859E-08 A8 -1.22068E-09 A10 0.00000E+00 M 24 κ 3.6281 A4 -1.21377E-04 A6 -7.10924E-07 A8 1.36403E-08 A10 -4.10781E-10 [Various Data] zoom ratio 9.42 W T f 10.30 ~ 97.00 FNO 4.12 ~ 6.48 ω 43.07 ~ 4.70° Y 8.19 ~ 8.19 W M T f 10.30000 50.00001 96.99995 ω 43.07103 9.11914 4.70123 FNO 4.12 5.81 6.48 ϕ 6.80 7.90 7.90 TL 90.80323 122.13334 131.09941 d5 2.28937 28.97477 38.62002 d13 13.12572 3.71901 2.00000 d14 6.29895 3.32684 1.40000 d17 2.43367 5.40578 7.33262 d23 6.60623 3.30000 3.30000 BF 13.44928 30.80693 31.84677 [Lens Group Data] ST f G1 1 59.94630 G2 6 -8.99248 G3 15 24.34092 G4 18 71.07089(W), 75.48860(M), 75.48860(T) G4F 18 -112.21259 G4R 24 35.78226 [Values for Conditional Expression] (7) ndh = 1.950(L11), 1.954(L407) (8) vdh = 29.37(L11), 33.46(L407) (9) f1/(-f2) = 6.67 (10) (-f2)/f3 = 0.369 (11) |fh/f1| = 0.761(L11) (12) vdh4 = 33.46(L407) (13) vdp1 = 82.57(L12) (14) vdp4 = 82.57(L401)

[0361] FIGS. 13A, 13B and 13C are sectional views showing a variable magnification optical system according to a fifth example of the present application, in which FIG. 13A shows sectional view in a wide-angle end state, FIG. 13B shows sectional view in an intermediate focal length state, and FIG. 13C shows sectional view in a telephoto end state.

[0362] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state.

Sixth Example

[0363] FIGS. 14A, 14B and 14C are sectional views showing a variable magnification optical system according to a sixth example of the fourth embodiment of the present application, in which FIG. 14A shows sectional view in a wide-angle end state, FIG. 14B shows sectional view in an intermediate focal length state, and FIG. 14C shows sectional view in a telephoto end state.

[0364] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a fourth lens group G4 having positive refractive power.

[0365] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a convex surface facing the object side.

[0366] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a double concave negative lens L22, a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. The negative meniscus lens L21 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0367] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. An aperture stop S is disposed at the object side of the third lens group G3.

[0368] The fourth lens group G4 consists of, in order from the object side, a front group G4F having negative refractive power and a rear group G4R having positive refractive power.

[0369] The front group G4F consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a negative meniscus lens L402 having a convex surface facing the image side and a cemented lens constructed by a double concave negative lens L403 cemented with a positive meniscus lens L404 having a convex surface facing the object side. The negative lens L403 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0370] The rear group G4R consists of, in order from the object side, a double convex positive lens L405 and a cemented lens constructed by a double convex positive lens L406 cemented with a negative meniscus lens L407 having a concave surface facing the object side. The positive lens L405 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0371] Incidentally, in the variable magnification optical system according to the present example, a low pass filter as well as a glass cover for a sensor can be disposed between the fourth lens group G4 and the image plane.

[0372] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1 to the fourth lens group G4 along the optical axis and moving the aperture stop S in a body with the front group G4F in the fourth lens group G4 such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the

fourth lens group G4 is increased, and a distance between the aperture stop S and the third lens group G3 is decreased. In more detail, upon zooming, the first lens group G1 and the third lens group G3 are moved toward the object side. The second lens group G2 is moved toward the object side from the wide-angle end state to the intermediate focal length state and toward the image side from the intermediate focal length state to the telephoto end state. In the fourth lens group G4, upon zooming from the wide-angle end state to the telephoto end state, the front group G4F and the rear group G4R are moved toward the object side such that a distance between the front group G4F and the rear group G4R is decreased.

[0373] Table 6 below shows various values of the variable magnification of the present example.

TABLE-US-00006 TABLE 6 Sixth Example [Surface Data] m r d nd vd OP ∞ 1 149.8692 1.6000 1.949665 27.56 2 44.3736 6.8398 1.497820 82.51 3 -243.5058 0.1000 4 45.3756 5.3508 1.867900 41.78 5 311.4136 d5 *6 89.0243 1.2000 1.834810 42.73 7 8.4900 3.7581 8 -15.7255 1.0000 1.834810 42.73 9 250.0000 0.1000 10 25.2749 3.2925 1.808090 22.74 11 -17.4750 0.5480 12 -12.6196 1.0000 1.816000 46.59 13 -33.4252 d13 14 ∞ d14 Aperture Stop S 15 29.1681 1.0000 1.889044 39.77 16 18.2404 3.2071 1.593125 66.16 17 -26.5261 d17 18 14.2857 3.5654 1.497820 82.51 19 -21.9776 1.0000 1.902000 25.23 20 -82.8398 2.2052 *21 -52.3071 1.0000 1.848976 43.01 22 9.1414 2.6915 1.950000 29.37 23 25.8642 d23 *24 35.4414 3.3350 1.589130 61.22 25 -21.3191 0.3000 26 42.3100 4.4029 1.581440 40.98 27 -10.1979 1.2000 1.954000 33.46 28 -300.4717 BF I ∞ [Aspherical Surface Data] m 6 κ 1.0000 A4 3.45801E-05 A6 -1.38520E-07 A8 -5.59965E-11 A10 1.26030E-11 m 21 κ 1.0000 A4 1.74477E-06 A6 1.28096E-07 A8 -2.63692E-09 A10 0.00000E+00 m 24 κ 1.0000 A4 -1.22983E-05 A6 1.47314E-07 A8 -5.48742E-10 A10 0.00000E+00 [Various Data] zoom ratio 9.42 W T f 10.30 ~ 97.00 FNO 3.50 ~ 5.62 ω 39.90 ~ 4.69° Y 8.19 ~ 8.19 W M T f 10.30001 49.99971 96.99932 ω 39.90076 9.01930 4.68610 FNO 3.50 5.20 5.62 ϕ 8.99 8.81 9.00 TL 99.25773 129.21001 139.67596 d5 1.99991 30.68218 41.26022 d13 18.53440 4.14191 2.00000 d14 3.76478 2.96318 1.40000 d17 3.54181 4.34341 5.90655 d23 8.01786 3.30678 3.30001 BF 14.70262 35.07621 37.11281 [Lens Group Data] ST f G1 1 66.85483 G2 6 -9.36043 G3 15 27.88295 G4 18 53.04244(W), 55.61603(M), 55.61991(T) G4F 18 -160.91663 G4R 24 33.55859 [Values for Conditional Expression] (7) ndh = 1.950(L404), 1.954(L407) (8) vdh = 29.37(L404), 33.46(L407) (9) f1/(-f2) = 7.14 (10) (-f2)/f3 = 0.336 (12) vdh4 = 33.46(L407) (13) vdp1 = 82.51(L12) (14) vdp4 = 82.51(L401)

[0374] FIGS. 15A, 15B and 15C are graphs showing various aberrations of the variable magnification optical system according to the sixth example of the present application upon focusing on an infinitely distant object, in which FIG. 15A is in a wide-angle end state, FIG. 15B is in an intermediate focal length state, and FIG. 15C is in a telephoto end state.

[0375] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state.

Seventh Example

[0376] FIGS. 16A, 16B and 16C are sectional views showing a variable magnification optical system according to a seventh example of the fourth embodiment of the present application, in which FIG. 16A shows sectional view in a wide-angle end state, FIG. 16B shows sectional view in an intermediate focal length state, and FIG. 16C shows sectional view in a telephoto end state.

[0377] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a fourth lens group G4 having positive refractive power.

[0378] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a positive meniscus lens L13 having a

convex surface facing the object side.

[0379] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a negative meniscus lens L22 having a concave surface facing the object side, a double convex positive lens L23 and a negative meniscus lens L24 having a concave surface facing the object side. Meanwhile, the negative meniscus lens L21 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped.

[0380] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32. Meanwhile, an aperture stop S is disposed at the object side of the third lens group G3.

[0381] The fourth lens group G4 consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a negative meniscus lens L402 having a convex surface facing the image side, a cemented lens constructed by a positive meniscus lens L403 having a concave surface facing the object side cemented with a double concave negative lens L404, a double convex positive lens L405, a cemented lens constructed by a positive meniscus lens L406 having a concave surface facing the object side cemented with a double concave negative lens L407, a cemented lens constructed by a negative meniscus lens L408 having a convex surface facing the object side cemented with a double convex positive lens L409, and a negative meniscus lens L410 having a concave surface facing the object side. Meanwhile, the positive meniscus lens L403 is a glass mold type aspherical lens whose object side lens surface is aspherically shaped, and the negative meniscus lens L410 is a glass mold type aspherical lens whose image side lens surface is aspherically shaped.

[0382] Incidentally, in the variable magnification optical system according to the present example, a low pass filter as well as a glass cover for a sensor can be disposed between the fourth lens group G4 and the image plane.

[0383] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1 to the fourth lens group G4 along the optical axis and moving the aperture stop S in a body with the fourth lens group G4 such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is increased, and a distance between the aperture stop S and the third lens group G3 is decreased. In more detail, upon zooming, the first lens group G1, the third lens group G3 and the fourth lens group G4 are moved toward the object side. The second lens group G2 is moved toward the object side from the wide-angle end state to the intermediate focal length state and toward the image side from the intermediate focal length state to the telephoto end state.

[0384] Table 7 below shows various values of the variable magnification of the present example.

TABLE-US-00007 TABLE 7 Seventh Example [Surface Data] m r d nd vd OP ∞ 1 134.9416
1.6000 2.001000 29.14 2 37.4620 7.6500 1.497820 82.57 3 -339.5674 0.1000 4 41.6639
5.5500 1.883000 40.66 5 520.6025 d5 *6 2429.7649 1.0000 1.851350 40.10 7 8.6673 5.7500 8
-10.8429 1.0000 1.487490 70.31 9 -45.5363 0.8500 10 52.5147 3.1000 1.808090 22.74 11
-17.4657 0.3000 12 -16.1357 1.0000 1.954000 33.46 13 -39.2793 d13 14 ∞ d14 Aperture Stop S
15 29.3843 1.0000 1.902650 35.73 16 14.8567 2.8000 1.719990 50.27 17 -55.5590 d17 18
13.5564 3.3500 1.497820 82.57 19 -24.9755 1.0000 1.950000 29.37 20 -183.0794 2.1500 *21
-145.2052 2.2500 1.802440 25.55 22 -14.7800 1.0000 1.766840 46.78 23 23.7425 2.8000 24
25.8106 3.0000 1.516800 63.88 25 -15.0644 0.1000 26 -568.8377 3.0000 1.568830 56.00 27
-9.3137 1.0000 1.954000 33.46 28 98.3635 0.1000 29 15.0059 1.0000 1.950000 29.37 30 7.0809
4.2500 1.647690 33.73 31 -21.2496 1.4500 32 -11.4669 1.0000 1.743300 49.32 *33 -29.8012
BF I ∞ [Aspherical Surface Data] m 6 κ -20.0000 A4 9.19258E-05 A6 -6.71049E-07 A8
3.76181E-09 A10 -1.11659E-11 m 21 κ -13.2727 A4 1.25451E-05 A6 1.56196E-07 A8

-2.20815E-09 A10 0.00000E+00 m 33 κ -0.9208 A4 -8.91367E-05 A6 -1.72158E-06 A8
2.40673E-08 A10 -6.77013E-10 [Various Data] Zoom ratio 9.42 W T f 10.30 ~ 97.00 FNO 4.08 ~
5.83 ω 40.21 ~ 4.78° Y 8.19 ~ 8.19 W M T f 10.30000 50.00021 97.00042 ω 40.21108 9.16962
4.78008 FNO 4.08 5.79 5.83 φ 8.40 9.20 10.10 TL 102.69006 133.09448 142.59913 d5 2.10000
29.30442 39.87067 d13 19.87565 4.17251 2.00000 d14 4.49060 3.80672 1.60000 d17 3.02442
3.70831 5.91502 BF 14.04941 32.95254 34.06346 [Lens Group Data] ST f G1 1 63.95755 G2 6
-10.21809 G3 15 32.27954 G4 18 70.96006 [Values for Conditional Expression] (7) ndh =
2.001(L11), 1.954(L24), 1.950(L402), 1.954(L407), 1.950(L408) (8) vdh = 29.14(L11),
33.46(L24), 29.37(L402), 33.46(L407), 29.37(L408) (9) f1/(-f2) = 6.26 (10) (-f2)/f3 = 0.317 (11)
|fh/f1| = 0.817(L11) (12) vdh4 = 33.46(L407) (13) vdp1 = 82.57(L12) (14) vdp4 = 82.57(L401)

[0385] FIGS. 17A, 17B and 17C are graphs showing various aberrations of the variable magnification optical system according to the seventh example of the present application upon focusing on an infinitely distant object, in which FIG. 17A is in a wide-angle end state, FIG. 17B is in an intermediate focal length state, and FIG. 17C is in a telephoto end state.

[0386] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state.

Eighth Example

[0387] FIGS. 18A, 18B and 18C are sectional views showing a variable magnification optical system according to an eighth example of the fourth embodiment of the present application, in which FIG. 18A shows sectional view in a wide-angle end state, FIG. 18B shows sectional view in an intermediate focal length state, and FIG. 18C shows sectional view in a telephoto end state.

[0388] The variable magnification optical system according to the present example is composed of, in order from an object side: a first lens group G1 having positive refractive power; a second lens group G2 having negative refractive power; a third lens group G3 having positive refractive power; and a fourth lens group G4 having positive refractive power.

[0389] The first lens group G1 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L11 having a convex surface facing the object side cemented with a double convex positive lens L12, and a plano-convex lens L13 having a convex surface facing the object side.

[0390] The second lens group G2 consists of, in order from the object side, a negative meniscus lens L21 having a convex surface facing the object side, a negative meniscus lens L22 having a concave surface facing the object side, a cemented lens constructed by a double convex positive lens L23 cemented with a negative meniscus lens L24 having a concave surface facing the object side. Meanwhile, the negative meniscus lens L21 is a compound type aspherical lens whose object side glass surface is provided with a resin layer.

[0391] The third lens group G3 consists of, in order from the object side, a cemented lens constructed by a negative meniscus lens L31 having a convex surface facing the object side cemented with a double convex positive lens L32.

[0392] The fourth lens group G4 consists of, in order from the object side, a cemented lens constructed by a double convex positive lens L401 cemented with a negative meniscus lens L402 having a convex surface facing the image side, a cemented lens constructed by a positive meniscus lens L403 having a concave surface facing the object side cemented with a double concave negative lens L404, a double convex positive lens L405, a cemented lens constructed by a double convex positive lens L406 cemented with a double concave negative lens L407, a cemented lens constructed by a double convex positive lens L408 cemented with a negative meniscus lens L409 having a convex surface facing the image side, and a negative meniscus lens L410 having a concave surface facing the object side. Meanwhile, the negative meniscus lens L404 is a glass mold type aspherical lens whose image side lens surface is aspherically shaped, and the negative meniscus lens L410 is a glass mold type aspherical lens whose image side lens surface is

aspherically shaped.

[0393] Incidentally, in the variable magnification optical system according to the present example, a low pass filter as well as a glass cover for a sensor can be disposed between the fourth lens group G4 and the image plane I.

[0394] In the variable magnification optical system according to the present example, zooming from the wide-angle end state to the telephoto end state, is conducted by moving the first lens group G1 to the fourth lens group G4 along the optical axis toward the object side and moving the aperture stop S in a body with the fourth lens group G4 such that a distance between the first lens group G1 and the second lens group G2 is increased, a distance between the second lens group G2 and the third lens group G3 is decreased, a distance between the third lens group G3 and the fourth lens group G4 is increased from the wide-angle end state to the intermediate focal length state and is decreased from the intermediate focal length state to the telephoto end state, and a distance between the aperture stop S and the third lens group G3 is increased from the wide-angle end state to the intermediate focal length state and is decreased from the intermediate focal length state to the telephoto end state.

[0395] Table 8 below shows various values of the variable magnification of the present example.

TABLE-US-00008 TABLE 8 Eighth Example [Surface Data] m r d nd vd OP ∞ 1 145.1831
1.7000 2.001000 29.14 2 36.6390 8.1000 1.497820 82.57 3 -399.3519 0.1000 4 43.2076
6.0000 1.883000 40.66 5 ∞ d5 *6 436.5967 0.1000 1.553890 38.09 7 87.0031 1.1000 1.834810
42.73 8 8.3001 5.3500 9 -12.6073 1.0000 1.755000 52.34 10 -32.7993 0.8000 11 41.1197
2.9500 1.808090 22.74 12 -19.6043 0.9000 1.883000 40.66 13 -73.1316 d13 14 ∞ d14 Aperture
Stop S 15 22.3725 0.9000 1.902650 35.73 16 12.2299 3.4500 1.670030 47.14 17 -59.6992 d17 18
13.7390 3.6000 1.497820 82.57 19 -24.8201 0.9000 2.000690 25.46 20 -270.0138 2.2000 21
-117.0547 2.0500 1.846660 23.80 22 -15.9850 1.0000 1.773770 47.25 *23 24.1750 2.0836 24
66.3654 2.8000 1.568830 56.00 25 -15.4473 0.1000 26 44.9939 2.7500 1.517420 52.20 27
-15.2012 0.9000 1.903660 31.27 28 29.9926 0.3000 29 14.6093 5.0500 1.672700 32.19 30
-9.1997 0.9000 2.000690 25.46 31 -24.3892 1.4000 32 -12.8617 1.0000 1.851350 40.10 *33
-27.4946 BF I ∞ [Aspherical Surface Data] m 6 κ 20.0000 A4 9.17458E-05 A6 -6.51986E-07 A8
2.69890E-09 A10 -1.23751E-11 m 23 κ 0.4823 A4 -7.24815E-06 A6 -3.60139E-07 A8
4.05630E-09 A10 0.00000E+00 m 33 κ -20.0000 A4 -1.22780E-04 A6 8.28360E-07 A8
-6.05245E-09 A10 -9.88805E-11 [Various Data] zoom ratio 9.42 W T f 10.30 ~ 96.99 FNO 4.12
~ 5.81 ω 40.44 ~ 4.73° Y 8.19 ~ 8.19 W M T f 10.30260 30.00000 96.99284 ω 40.44283 14.85841
4.72723 FNO 4.12 5.48 5.81 ϕ 8.12 8.12 9.70 TL 103.02710 121.37977 143.32397 d5 2.10606
20.13084 40.20889 d13 19.66416 6.24359 1.80000 d14 4.27874 4.97381 1.80000 d17 3.43763
2.74256 5.91637 BF 14.05688 27.80535 34.11509 [Lens Group Data] ST f G1 1 64.09778 G2 6
-10.16794 G3 15 31.06055 G4 18 67.05869 [Values for Conditional Expression] (7) ndh =
2.001(L11) (8) vdh = 29.14(L11) (9) f1/(-f2) = 6.31 (10) (-f2)/f3 = 0.327 (11) |fh/f1| =
0.770(L11) (13) vdp1 = 82.57(L12) (14) vdp4 = 82.57(L401)

[0396] FIGS. 19A, 19B and 19C are graphs showing various aberrations of the variable magnification optical system according to the eighth example of the present application upon focusing on an infinitely distant object, in which FIG. 19A is in a wide-angle end state, FIG. 19B is in an intermediate focal length state, and FIG. 19C is in a telephoto end state.

[0397] As is apparent from the respective graphs, the variable magnification optical system according to the present example shows superb optical performance as a result of good corrections to various aberrations from the wide-angle end state to the telephoto end state.

[0398] According to the fourth to the eighth examples, a variable magnification optical system that is downsized and has high optical performance can be realized.

[0399] Incidentally, the above described examples each only shows a specific example of the invention of the present application, and accordingly the present invention is not limited to them. The following description may suitably be applied within limits that do not deteriorate optical

performance of the variable magnification optical system according to the first to the fourth embodiments of the present application.

[0400] As the numerical examples of the variable magnification optical system according to the first to the fourth embodiments of the present application, although zoom lenses having a four-lens-group configuration and a five-lens-group configuration have been shown, the present application are not limited to them and can be applied to other lens configurations such as a six-lens-group configuration. Specifically, a lens configuration in which a lens or a lens group is added to the most object side, or the most image side of the variable magnification optical system according to the first to the fourth embodiments of the present application is possible. Incidentally, a lens group is defined as a portion including at least one lens separated by air spaces.

[0401] In a variable magnification optical system according to the first to the fourth embodiments of the present application, in order to vary focusing from infinitely distant object to a close object, a portion of a lens group, a single lens group, or a plurality of lens groups may be moved along the optical axis as a focusing lens group. It is particularly preferable that at least a portion of the second lens group, a portion of the third lens group or a portion of the fourth lens group is moved as the focusing lens group. In this case, the focusing lens group can be used for auto focus, and suitable for being driven by a motor such as an ultrasonic motor.

[0402] Moreover, in a variable magnification optical system according to the first to the fourth embodiments of the present application, a lens group as a whole or a portion of a lens group may be moved as a vibration reduction lens group to have a component in a direction perpendicular to the optical axis, or tilted (swayed) in a direction including the optical axis, thereby correcting an image blur caused by a camera shake. In particular, at least a portion of the third lens group or a portion of the fourth lens group is preferably made as the vibration reduction lens group.

[0403] In a variable magnification optical system according to the first to the fourth embodiments of the present application, any lens surface may be a spherical surface, a plane surface, or an aspherical surface. When a lens surface is a spherical surface or a plane surface, lens processing, assembling and adjustment become easy, and deterioration in optical performance caused by lens processing, assembling and adjustment errors can be prevented, so that it is preferable. Moreover, even if the image plane is shifted, deterioration in optical performance is little, so that it is preferable. When a lens surface is an aspherical surface, the aspherical surface may be fabricated by a fine grinding process, a glass molding process that a glass material is formed into an aspherical shape by a mold, or a compound type process that a resin material is formed into an aspherical shape on a glass lens surface. A lens surface may be a diffractive optical surface, and a lens may be a graded-index type lens (GRIN lens) or a plastic lens.

[0404] In a variable magnification optical system according to the first to the fourth embodiments of the present application, although an aperture stop is preferably disposed in the third lens group or in the neighborhood of the third lens group, the function may be substituted by a lens frame without disposing a member as an aperture stop.

[0405] Moreover, the lens surface of the lenses composing the variable magnification optical system according to the first to the fourth embodiments of the present application may be applied with an anti-reflection coating having a high transmittance in a broad wavelength range. With this contrivance, it is feasible to attain the high contrast and the high optical performance by reducing a flare and ghost images.

[0406] In a variable magnification optical system according to the first to the fourth embodiments of the present application, the zoom ratio is about 5 to 20.

[0407] Next, a camera, which is an optical apparatus equipped with the variable magnification optical system according to the first to the fourth embodiments of the present application, is explained with referring to FIG. 20.

[0408] FIG. 20 is a view showing a configuration of a camera equipped with the variable magnification optical system according to the first to the fourth embodiments of the present

application.

[0409] In FIG. 20, the camera 1 is a so-called mirror-less camera of a lens interchangeable type equipped with the variable magnification optical system according to the first to the fourth embodiments of the present application as an imaging lens 2.

[0410] In the camera 1, light emitted from an unillustrated object is converged by the imaging lens 2, through an OLPF (optical low pass filter), and forms an object image on an imaging surface of an imaging portion 3. The object image is photo-electrically converted by a photo-electric conversion element provided in the imaging portion 3 so that a picture of the object is formed. This picture is displayed on an EVF (Electronic view finder) 4. Thus, a photographer can observe the object through the EVE 4.

[0411] When the photographer presses an unillustrated release button, the picture of the object formed by the imaging portion 3 is stored in an unillustrated memory. In this manner, the photographer can take a picture of the object by the camera 1.

[0412] Here, the variable magnification optical system according to the first example installed in the camera 1 as the imaging lens 2 is a variable magnification optical system that has an excellent optical performance. Accordingly, the camera 1 can realize excellent optical performance. Further, even if a variable magnification optical system according to the second to the eighth examples is installed in a camera as an imaging lens 2, the same effect as that of the camera 1 can be attained. Further, even if a variable magnification optical system according to each of the above described examples is installed in a single lens reflex camera of the type which is provided with a quick return mirror and in which an object is observed through a finder optical system, the same effect as that of the camera 1 can be attained.

[0413] Finally, an outline of a method for manufacturing a variable magnification optical system according to the first to the fourth embodiments of the present application, is described with referring to FIG. 21 to FIG. 24.

[0414] The method for manufacturing the variable magnification optical system according to the first embodiment of the present application shown in FIG. 21, is a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group; and the method comprises the following steps of S11 to S14:

[0415] Step S11: disposing each lens group and the aperture stop, in order from the object side, in a lens barrel, and constructing, by providing a known movement mechanism in the lens barrel, such that, upon zooming from a wide angle end state to a telephoto end state, at least the rear lens group is moved toward the object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group are varied.

[0416] Step S12: providing a known movement mechanism in the lens barrel and constructing such that, upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis. Step S13: providing a known movement mechanism and constructing at least a portion of the rear lens group to be moved to have a component in a direction perpendicular to the optical axis, as a vibration reduction lens group.

[0417] Step S14: constructing such that the vibration reduction lens group has negative refractive power.

[0418] Thus, the method for manufacturing a variable magnification optical system according to the first embodiment of the present application makes it possible to manufacture a variable magnification optical system that has high zoom ratio, is downsized and has excellent optical performance.

[0419] The method for manufacturing the variable magnification optical system according to the

second embodiment of the present application shown in FIG. 22, is a method for manufacturing 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 rear lens group; and the method comprises the following steps of S21 to S25:

[0420] Step S21: disposing respective lens groups, in order from the object side, in a lens barrel, and constructing, by providing a known movement mechanism in the lens barrel, such that, upon zooming from a wide-angle end state to a telephoto end state, at least the first lens group and the rear lens group are moved toward the object side, and that a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group are varied.

[0421] Step S22: providing a known movement mechanism in the lens barrel and constructing such that, upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis. Step S23: providing a known movement mechanism and constructing at least a portion of the rear lens group to be moved to have a component in a direction perpendicular to the optical axis, as a vibration reduction lens group.

[0422] Step S24: constructing such that the vibration reduction lens group has negative refractive power.

[0423] Step S25: constructing such that the third lens group and the vibration reduction lens group satisfy the following conditional expression (3):

$$[00029] \quad 0.20 < (-f_{VR}) / f_3 < 1.2 \quad (3)$$

where f_{VR} denotes a focal length of the vibration reduction lens group, and f_3 denotes a focal length of the third lens group.

[0424] Thus, the method for manufacturing a variable magnification optical system according to the second embodiment of the present application makes it possible to manufacture a variable magnification optical system that has high zoom ratio, is downsized and has excellent optical performance.

[0425] The method for manufacturing the variable magnification optical system according to the third embodiment of the present application shown in FIG. 23, is a method for manufacturing 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; an aperture stop; a third lens group having positive refractive power; and a rear lens group; and the method comprises the following steps of S31 to S33:

[0426] Step S31: constructing such that the third lens group is composed of a cemented lens constructed by a positive lens and a negative lens.

[0427] Step S32: disposing each lens group and the aperture stop, in order from the object side, in a lens barrel, and constructing, by providing a known movement mechanism in the lens barrel, such that, upon zooming from a wide-angle end state to a telephoto end state, at least the rear lens group is moved toward the object side, and a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group and a distance between the third lens group and the rear lens group are varied.

[0428] Step S33: providing a known movement mechanism in the lens barrel and constructing such that, upon focusing on from an infinitely distant object to a closely distant object, the third lens group as a whole is moved in the direction of the optical axis.

[0429] Thus, the method for manufacturing a variable magnification optical system according to the third embodiment of the present application makes it possible to manufacture a variable magnification optical system that has high zoom ratio, is downsized and has excellent optical performance.

[0430] The method for manufacturing the variable magnification optical system according to the fourth embodiment of the present application shown in FIG. 24, is a method for manufacturing 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 fourth lens group having positive refractive power; and the method comprises the following steps of S41 to S42:

[0431] Step S41: disposing each lens group in a lens barrel in order from the object side such that the variable magnification optical system has at least one lens that satisfies the following conditional expressions (7) and (8):

[00030] $1.928 < ndh$ (7) $28.6 < vdh$ (8)

where ndh denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the said lens, and vdh denotes Abbe number at d-line (wavelength $\lambda=587.6$ nm) of the said lens.

[0432] Step S42: providing a known movement mechanism in the lens barrel and constructing such that, upon focusing from an infinitely distant object to a closely distant object, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the fourth lens group are varied.

[0433] Thus, the method for manufacturing a variable magnification optical system according to the fourth embodiment of the present application makes it possible to manufacture a variable magnification optical system that is downsized and has excellent optical performance.

Claims

1. (canceled)

2. 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 rear lens group; upon zooming, a distance between the first lens group and the second lens group, a distance between the second lens group and the third lens group, and a distance between the third lens group and the rear lens group being varied; upon zooming, the first lens group being moved such that a position of the first lens group in a telephoto end state is more object side than the position of the first lens group in a wide-angle end state; upon zooming, the third lens group being moved; and the first lens group having a negative lens that satisfies the following conditional expression:

$1.90 < nd1$ where $nd1$ denotes refractive index at d-line (wavelength $\lambda=587.6$ nm) of the negative lens in the first lens group.

3. The variable magnification optical system according to claim 2, wherein the following conditional expression is satisfied: $0.6 < f1 / f3 < 2.60$ where $f1$ denotes a focal length of the first lens group and $f3$ denotes a focal length of the third lens group.

4. The variable magnification optical system according to claim 3, wherein the following conditional expression is satisfied: $0.10 < (-f2) / f3 < 0.38$ where $f2$ denotes a focal length of the second lens group.

5. The variable magnification optical system according to claim 2, wherein an aperture stop is disposed between the second lens group and the third lens group.

6. The variable magnification optical system according to claim 5, wherein upon zooming, the second lens group is moved.

7. An optical apparatus equipped with the variable magnification optical system according to claim 2.
