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(54) **WAVEGUIDE ROD FOR ULTRASONIC SCALPEL**

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(57) **ABSTRACT**

A waveguide rod for an ultrasonic scalpel having a relatively desirable amplitude and frequency comprises a proximal gain structure, a distal gain structure, an intermediate structure, and a frequency adjustment structure. The proximal gain structure and the intermediate structure are connected in a position near an antinode of longitudinal vibration of the waveguide rod through a proximal side gain step. The distal gain structure and the intermediate structure are connected in a position near an antinode of the longitudinal vibration of the waveguide rod through a distal side gain step. The intermediate structure comprises N (N>0, and N is an integer) gain holding structures that are connected two by two in a position near an antinode of the longitudinal vibration of the waveguide rod through an intermediate gain step. X (X>0, and X is an integer) frequency adjustment structures exist on the gain holding structure. The waveguide rod provides an ultrasonic scalpel with a relatively large blade amplitude and also enables the ultrasonic scalpel to work at a stable and suitable vibration frequency, so that the ultrasonic scalpel can cut human tissue efficiently.

Normalized
Amplitude

Normalized Length

FIG. 1

Normalized
Amplitude

Normalized Length

FIG. 2

Normalized Amplitude

Normalized Length

FIG. 3

Normalized Amplitude

Normalized Length

FIG. 4

Normalized Length

FIG. 5

WAVEGUIDE ROD FOR ULTRASONIC SCALPEL

TECHNICAL FIELD

[0001] This application relates to ultrasonic surgical instruments, and specifically, to an ultrasonic scalpel having a waveguide rod.

BACKGROUND ART

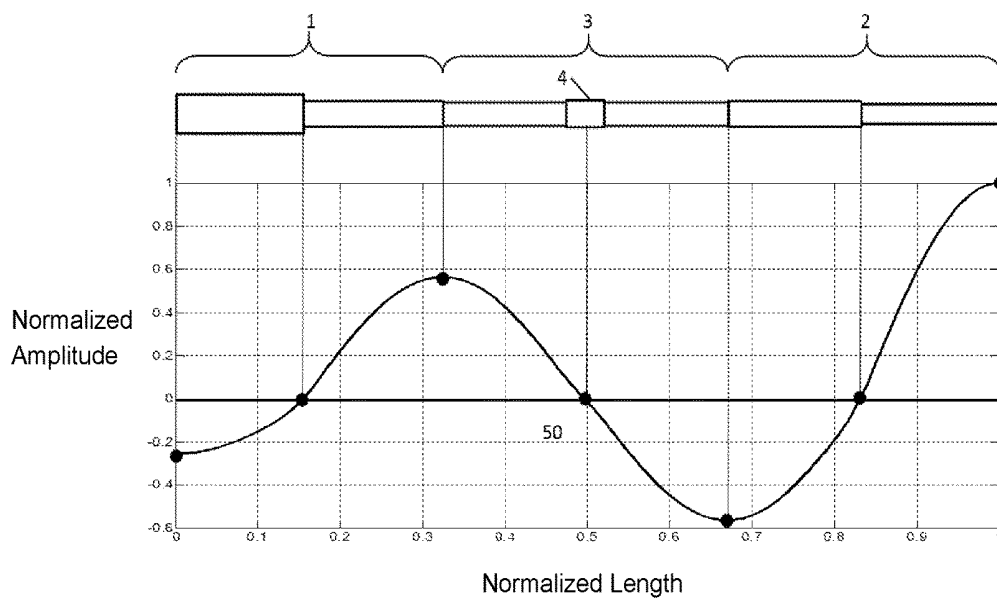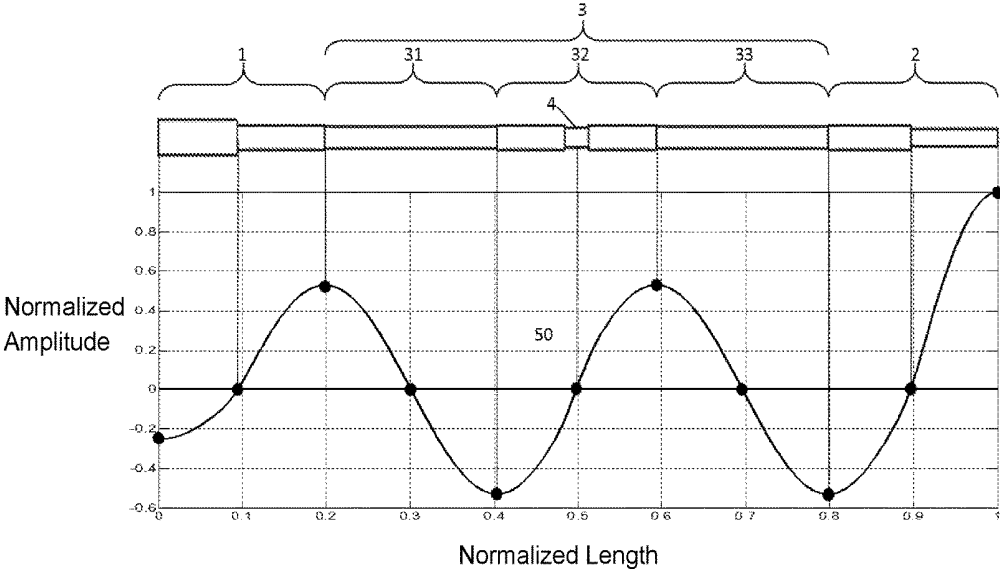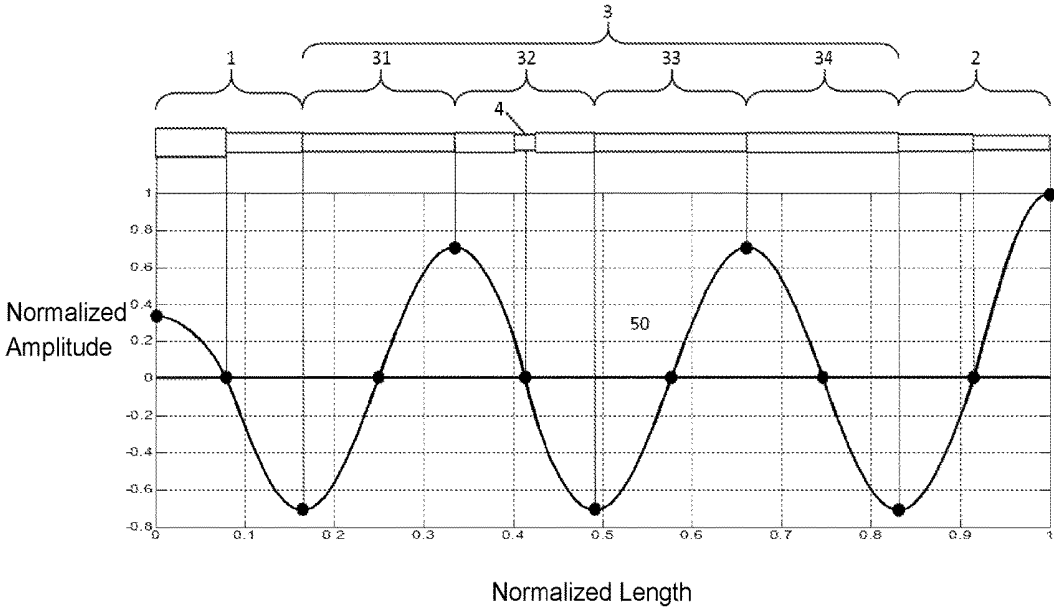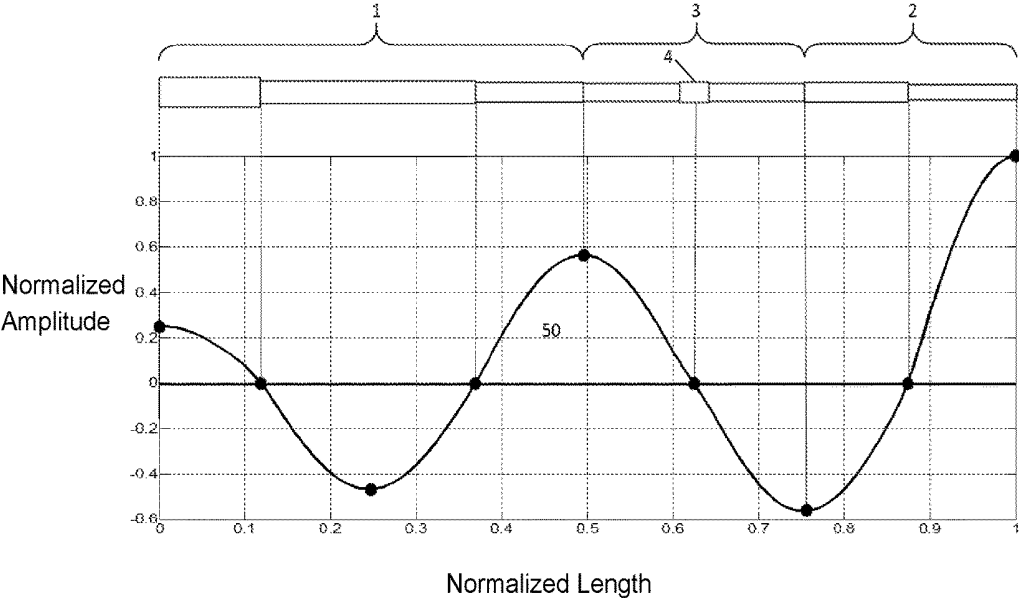[0002] In current clinical fields, due to advantages such as neat incisions, rapid hemostasis, small thermally damaged regions, and little smoke, ultrasonic scalpels have been used increasingly widely in place of conventional minimally invasive surgical instruments such as high-frequency electric scalpels and mechanical clamps. The ultrasonic scalpel uses an ultrasonic frequency generator to generate mechanical vibration in a blade at a particular ultrasonic frequency to vaporize water molecules in tissue, break hydrogen bonds in proteins, and wreck cells, so as to achieve the objective of tissue cutting, blood coagulation, and vascular closure. Related researches proved (see "Working Principles and Clinical Applications of Ultrasonic Scalpels", LIN Guoqing, QU Zhe, Chinese Medical Equipment Journal, 2008, and "Optimized Design of Ultrasonic Scalpels", ZHOU Hongsheng, XU Xiaofang, et al., Technical Acoustics, February, 2012) that when a mechanical vibration whose particle acceleration is 5×10^4 g (g is the gravitational acceleration) is applied on living biological tissue, the position where the mechanical vibration is applied can be cut open rapidly without damaging surrounding tissue. A relationship among the amplitude, frequency, and acceleration of a blade of an ultrasonic scalpel is: $a=A(2\pi f)^2$, wherein a is an acceleration, A is an amplitude, and f is a vibration frequency. Therefore, the vibration frequency and amplitude of the blade of the ultrasonic scalpel represent a cutting capability of the blade of the ultrasonic scalpel.

[0003] An ultrasonic scalpel generally comprises a main unit, a transducer, a waveguide rod, a blade, an auxiliary mechanism connecting and supporting the foregoing parts, and other accessories. The main unit generates a high-frequency current. The transducer converts the high-frequency current into an ultrasound vibration. Ultrasonic energy is then transferred to the blade through the waveguide rod. The blade contacts human tissue and friction is generated between the blade and the human tissue to produce effects of mechanical cutting and blood coagulation. Generally, the transducer and the waveguide rod are threaded together, and the waveguide rod and the blade may be threaded, welded or directly integrated. During normal working, the transducer, the waveguide rod, and the blade resonate at a resonance frequency. During transfer of the ultrasound vibration from the transducer to the blade through the waveguide rod, in one aspect, the vibration needs to be amplified to provide the blade with a sufficient amplitude, and in another aspect, the waveguide rod is a critical factor for keeping a vibration frequency of the blade stable and suitable. Therefore, the design of the waveguide rod needs to consider both a vibration frequency and an amplitude gain. Persons skilled in the art are always seeking for a waveguide rod structure that has both a stable and suitable vibration frequency and a relatively large amplitude gain.

[0004] Patent CN200480036431.8 discloses an ultrasonic scalpel having a gain step, wherein a distance between a gain step and a vibration node on a waveguide rod is set to obtain a relatively large blade amplitude. Patent CN201410068159.7 discloses an ultrasonic scalpel having a waveguide rod with a periodically repetitive structure. The repetitive structure can enable the ultrasonic scalpel to work at a stable frequency. However, the structures disclosed in the foregoing patent deal with only one of an amplitude and a frequency of a waveguide rod rather than take both an amplitude and a frequency into consideration.

Summary of this Application

[0005] In view of the foregoing deficiencies in the prior art, this application provides a novel waveguide rod structure for an ultrasonic scalpel, so that an ultrasonic scalpel can have a relatively large blade amplitude and also can work at a stable and suitable vibration frequency. Therefore, the ultrasonic scalpel can cut human tissue efficiently.

[0006] To resolve the foregoing technical problem, the Invention adopts the following technical solution:

A waveguide rod for an ultrasonic scalpel comprises a proximal gain structure, a distal gain structure, an intermediate structure, and a frequency adjustment structure on the intermediate structure.

[0007] The proximal gain structure and the intermediate structure are connected in a position near an antinode of longitudinal vibration of the waveguide rod through a proximal side gain step.

[0008] A gain of the proximal side gain step is greater than or less than a unit gain, and a distance between the proximal side gain step and the antinode is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod. Preferably, the proximal side gain step is located in a position of the antinode.

[0009] The distal gain structure and the intermediate structure are connected in a position near an antinode of the longitudinal vibration of the waveguide rod through a distal side gain step. A gain of the distal side gain step is greater than or less than a unit gain, and a distance between the distal side gain step and the antinode is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod. Preferably, the distal side gain step is located in a position of the antinode.

[0010] One or more proximal gain steps exist on the proximal gain structure, a gain of the proximal gain step is greater than a unit gain, the proximal gain step is in a position near a node of the longitudinal vibration of the waveguide rod, only zero or one most proximal gain step exists in a position near each node, and a distance between the proximal gain step and the node is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod. Preferably, the proximal gain step is located in a position of a node.

[0011] One or more distal gain steps exist on the distal gain structure, a gain of the distal gain step is greater than a unit gain, the distal gain step is in a position near a node of the longitudinal vibration of the waveguide rod, only zero or one most distal gain step exists in a position near each node, and a distance between the distal gain step and the node is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod. Preferably, the distal gain step is located in a position of a node.

[0012] The intermediate structure comprises N (N>0, and N is an integer) gain holding structures that are connected two by two in a position near an antinode of the longitudinal vibration of the waveguide rod through an intermediate gain step, and a distance between each intermediate gain step and the antinode is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod. Preferably, the intermediate gain step is located in a position of the antinode.

[0013] The frequency adjustment structure is disposed on the gain holding structure of the intermediate structure. A quantity of frequency adjustment structures is X (X>0, and X is an integer), and each frequency adjustment structure forms a front frequency modulation gain step and a rear frequency modulation gain step on a gain holding structure. Only one node of the longitudinal vibration of the waveguide rod exists between the front frequency modulation gain step and the rear frequency modulation gain step, a distance between the front frequency modulation gain step and the rear frequency modulation gain step is less than a distance between two antinodes of the longitudinal vibration that are adjacent to a node, and one of gains of the front frequency modulation gain step and the rear frequency modulation gain step is greater than a unit gain and the other of the gains is less than the unit gain.

[0014] According to this application, preferred implementation solutions of the proximal gain structure and the distal gain structure are: 1) The proximal gain structure is located in a range of a first half wavelength of the longitudinal vibration of the waveguide rod, and the proximal gain step is in a position near a first node of the longitudinal vibration of the waveguide rod. 2) The proximal gain structure is located in a range of first two half wavelengths of the longitudinal vibration of the waveguide rod, and the proximal gain step is in a position near a first or second node of the longitudinal vibration of the waveguide rod. 3) The distal gain structure is located in a range of a last half wavelength of the longitudinal vibration of the waveguide rod, and the distal gain step is in a position near a last node of the longitudinal vibration of the waveguide rod. 4) The distal gain structure is located in a range of last two half wavelengths of the longitudinal vibration of the waveguide rod, and the distal gain step is in a position near a last or a second last node of the longitudinal vibration of the waveguide rod. In addition, another implementation solution of the proximal gain structure and the distal gain structure that meets a requirement of this application is also protected by the Invention.

[0015] Further, a plurality of preferred implementation forms is used to implement that the intermediate structure comprises N (N>0, and N is an integer) gain holding structures that are connected two by two in a position near an antinode of the longitudinal vibration of the waveguide rod through an intermediate gain step. 1) A quantity N of the gain holding structures on the intermediate structure is equal to 1. 2) A quantity N of the gain holding structures on the intermediate structure is greater than 1, N is an odd number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is: a gain of each of a first intermediate gain step to an ((N−1)/2)th intermediate gain step is greater than a unit gain, and a gain of each of an ((N−1)/2+1)th intermediate gain step to an (N−1)th intermediate gain step is less than the unit gain. 3) A quantity N of the gain holding structures on the intermediate structure

is greater than 1, N is an odd number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is: a gain of each of a first intermediate gain step to an ((N−1)/2)th intermediate gain step is less than a unit gain, and a gain of each of an ((N−1)/2+1)th intermediate gain step to an (N−1)th intermediate gain step is greater than the unit gain. 4) A quantity N of the gain holding structures on the intermediate structure is greater than 1, N is an odd number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain greater than a unit gain and a gain less than the unit gain. 5) A quantity N of the gain holding structures on the intermediate structure is greater than 1, N is an odd number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain less than a unit gain and a gain greater than the unit gain. 6) The quantity N of the gain holding structures is equal to 2, and a gain of an intermediate gain step connecting two gain holding structures is greater than a unit gain. 7) The quantity N of the gain holding structures is equal to 2, and a gain of an intermediate gain step connecting two gain holding structures is less than a unit gain. 8) The quantity N of the gain holding structures is greater than 2, N is an even number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain greater than a unit gain and a gain less than the unit gain. 9) The quantity N of the gain holding structures is greater than 2, N is an even number, and a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain less than a unit gain and a gain greater than the unit gain. In addition, another implementation solution of the intermediate structure that meets a requirement of this application is also protected by the Invention.

[0016] Further, one or more frequency adjustment structures exist on some gain holding structures, and the frequency adjustment structure has two implementation forms: 1) For the front frequency modulation gain step and the rear frequency modulation gain step of the frequency adjustment structure, the gain of the front frequency modulation gain step is less than the unit gain, and the gain of the rear frequency modulation gain step is greater than the unit gain. 2) For the front frequency modulation gain step and the rear frequency modulation gain step of the frequency adjustment structure, the gain of the front frequency modulation gain step is greater than the unit gain, and the gain of the rear frequency modulation gain step is less than the unit gain.

[0017] In specific implementation manners of the waveguide rod for an ultrasonic scalpel, the Invention comprises different implementation manners of the foregoing proximal gain structure, distal gain structure, intermediate structure, and frequency adjustment structure.

[0018] The foregoing gain steps have a form selected from a stair form, a conical form, an exponential form or a catenary form.

[0019] Several benefits can be obtained from one or more implementation forms of the Invention. The waveguide rod for an ultrasonic scalpel of the Invention comprises a proximal gain structure, a distal gain structure, an intermediate structure, and a frequency adjustment structure. The proximal gain structure has a proximal gain step whose gain is greater than a unit gain in a position near a node of

longitudinal vibration of the waveguide rod. It is known to persons skilled in the art that a gain step in a position near a node can affect an amplitude gain significantly, wherein a gain step whose gain is greater than the unit gain can effectively amplify an amplitude, and a gain step whose gain is less than the unit gain can effectively attenuate an amplitude. Therefore, the proximal gain structure can provide the waveguide rod with a relatively large initial amplitude gain. Gain holding structures on the intermediate structure are connected two by two in a position near an antinode of the longitudinal vibration of the waveguide rod through an intermediate gain step. It is known to persons skilled in the art that a gain step in a position near an antinode affects an amplitude gain relatively slightly. Therefore, the intermediate structure can ensure that an amplitude of ultrasound is basically not attenuated or amplified during propagation of the ultrasound in the intermediate structure of the waveguide rod. Without attenuation, the effectiveness of amplitude amplification of the proximal gain structure can be kept. Without amplification, a loss during energy transfer can be reduced. Similar to the proximal gain structure, the distal gain structure has a distal gain step whose gain is greater than the unit gain in a position near a node of the longitudinal vibration of the waveguide rod, so that the waveguide rod can be provided with a relatively large secondary amplitude gain. In this way, the waveguide rod uses the proximal gain structure to provide a relatively large initial amplitude gain, uses the intermediate structure to basically keep the amplitude gain from attenuation and amplification, and then uses the distal gain structure to provide a relatively large secondary amplitude gain, so as to eventually provide a relatively large amplitude for the vibration of a blade. The frequency adjustment structure exists on some gain holding structures of the intermediate structure. The frequency adjustment structure is disposed in a position near a node of the longitudinal vibration of the waveguide rod, and two frequency modulation gain steps are formed before and after the node, wherein a gain of one frequency modulation gain step is greater than the unit gain, and a gain of the other frequency modulation gain step is less than the unit gain. Such a structural form only affects an amplitude gain relatively slightly but can effectively adjust a vibration frequency of the waveguide rod, so that the vibration frequency of the waveguide rod is stabilized in a suitable range. In this way, the waveguide rod that comprises the proximal gain structure, the distal gain structure, the intermediate structure, and the frequency adjustment structure can provide an ultrasonic scalpel with a relatively large amplitude during working and also can enable the ultrasonic scalpel to work stably at a suitable working frequency, so that human tissue can be cut efficiently.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. 1 shows a waveguide rod for an ultrasonic scalpel according to a first implementation manner of this application and a waveform generated along the waveguide rod.

[0021] FIG. 2 shows a waveguide rod for an ultrasonic scalpel according to a second implementation manner of this application and a waveform generated along the waveguide rod.

[0022] FIG. 3 shows a waveguide rod for an ultrasonic scalpel according to a third implementation manner of this application and a waveform generated along the waveguide rod.

[0023] FIG. 4 shows a waveguide rod for an ultrasonic scalpel according to a fourth implementation manner of this application and a waveform generated along the waveguide rod.

[0024] FIG. 5 shows a waveguide rod for an ultrasonic scalpel according to a fifth implementation manner of this application and a waveform generated along the waveguide rod.

DETAILED DESCRIPTION OF EMBODIMENTS

[0025] Referring to FIG. 1, FIG. 1 shows a waveguide rod for an ultrasonic scalpel according to a first implementation manner of this application and a waveform generated along the waveguide rod. The waveguide rod for an ultrasonic scalpel comprises a proximal gain structure 1, a distal gain structure 2, an intermediate structure 3, and frequency adjustment structures 41, 42, and 43. A curve 50 below the waveguide rod in FIG. 1 is an amplitude curve of longitudinal vibration of the waveguide rod, wherein a horizontal axis is a normalized length, and a vertical axis is a normalized amplitude. In the curve 50, 501 to 509 are nodes of the longitudinal vibration. The node 501 is a first node, the node 509 is a last node, and 510 to 519 are antinodes of the longitudinal vibration. The antinode 510 is a first antinode, and the antinode 519 is a last antinode. The proximal gain structure 1 and the intermediate structure 3 are connected through a proximal side gain step 13. A position of the proximal side gain step 13 is near the second antinode 511 of the longitudinal vibration, and a gain of the proximal side gain step 13 is greater than a unit gain. The distal gain structure 2 and the intermediate structure 3 are connected through a distal side gain step 23. A position of the distal side gain step 23 is near the second last antinode 518 of the longitudinal vibration, and a gain of the distal side gain step 23 is less than the unit gain.

[0026] The proximal gain structure 1 has a most proximal gain step 11 in a position near the first node 501 of the longitudinal vibration of the waveguide rod. A gain of the most proximal gain step 11 is greater than the unit gain. That is, the most proximal gain step 11 is an amplification step. The distal gain structure 2 has a most distal gain step 21 in a position near the last node 509 of the longitudinal vibration of the waveguide rod. A gain of the most distal gain step 21 is greater than the unit gain. That is, the most distal gain step 21 is an amplification step. The proximal gain structure 1 and the distal gain structure 2 set gain steps (that is, the most proximal gain step 11 and the most distal gain step 21) thereof in positions near a node, so that an amplitude gain can be effectively improved. An eventual amplitude gain of the entire waveguide rod is also mainly determined by the gains of the proximal gain structure 1 and the distal gain structure 2. As shown in FIG. 1, the most proximal gain step 11 enables an amplitude gain between the second antinode 511 and the first antinode 510 to be approximately 1.9, and the most distal gain step 21 enables an amplitude gain between the last antinode 519 and the second last antinode 518 to be approximately 3, so that the eventual amplitude gain of the waveguide rod can be up to 5.7. In this way, a relatively large amplitude can be generated in a blade of an ultrasonic scalpel.

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[0027] The intermediate structure of the waveguide rod **3** comprises N (N>0, and N is an integer) gain holding structures, and comprises three gain holding structures **31**, **32**, and **33** in the implementation manner in FIG. **1**. The first gain holding structure **31** and the second gain holding structure **32** are connected through an intermediate gain step **312**. A position of the intermediate gain step **312** is near the fourth antinode **513** of the longitudinal vibration, and a gain of the intermediate gain step **312** is greater than the unit gain. The second gain holding structure **32** and the third gain holding structure **33** are connected through an intermediate gain step **323**. A position of the intermediate gain step **323** is near the third last antinode **517** of the longitudinal vibration, and a gain of the intermediate gain step **323** is less than the unit gain. The applicant finds that the structure that the gain holding structures **31**, **32**, and **33** are connected two by two through a gain step in a position near an antinode of the longitudinal vibration can ensure that an amplitude of an ultrasound vibration is basically not attenuated or amplified during propagation of the ultrasound vibration in the intermediate structure of the waveguide rod, so as to facilitate more stable transfer of energy to the blade.

[0028] In some gain holding structures of the intermediate structure **3**, in the implementation manner shown in the intermediate structure **3**, the frequency adjustment structures **41**, **42**, and **43** are further disposed on the second gain holding structure **32**. Each frequency adjustment structure has a front frequency modulation gain step and a rear frequency modulation gain step. Referring to FIG. **1**, the frequency adjustment structure **43** is used as an example. The frequency adjustment structure **43** forms a front frequency modulation gain step **431** and a rear frequency modulation gain step **432** on the gain holding structure **32**. A gain of the front frequency modulation gain step **431** is less than the unit gain, and a gain of the rear frequency modulation gain step **432** is greater than the unit gain. Only one node **506** of the longitudinal vibration of the waveguide rod exists between the front frequency modulation gain step **431** and the rear frequency modulation gain step **432**. A distance between the front frequency modulation gain step and the rear frequency modulation gain step is less than a distance between the two antinodes **515** and **516** of the longitudinal vibration adjacent to the node **506**. The applicant finds that the vibration frequency of the waveguide rod can be adjusted by increasing or reducing a quantity of the frequency adjustment structures, increasing or reducing a distance between a front gain step and a rear gain step of the frequency adjustment structure or increasing or reducing gains of the front gain step and the rear gain step basically without affecting an amplitude eventually output by the waveguide rod. The foregoing frequency adjustment structures **41**, **42**, and **43** keep a resonance frequency of the waveguide rod in a required range, so that the ultrasonic scalpel can work stably at a suitable frequency.

[0029] According to the structural form in FIG. **1** of this application, the proximal gain structure **1** and the distal gain structure **2** provide a relatively large amplitude gain, so as to provide a relatively large amplitude for a vibration of the blade of the ultrasonic scalpel. The gain holding structures **31**, **32**, and **33** on the intermediate structure **3** can ensure that an amplitude of an ultrasound vibration is basically not attenuated or amplified during propagation of the ultrasound vibration in the intermediate structure of the waveguide rod. The frequency adjustment structures **41**, **42**, and **43** stabilize the vibration frequency of the waveguide rod in a suitable range. In this way, the ultrasonic scalpel can be provided with a relatively large amplitude during working and also can work stably at a suitable frequency, so that human tissue can be cut efficiently.

[0030] FIG. **2** shows a waveguide rod for an ultrasonic scalpel according to a second implementation manner of this application and a waveform generated along the waveguide rod. The implementation manner comprises a proximal gain structure **1**, a distal gain structure **2**, an intermediate structure **3**, and a frequency adjustment structure **4**. The proximal gain structure is in a range of a first half wavelength of longitudinal vibration of the waveguide rod, and a most proximal gain step is near a first node of the longitudinal vibration. The distal gain structure is in a range of a last half wavelength of the longitudinal vibration of the waveguide rod, and a most distal gain step is near a last node of the longitudinal vibration. The proximal gain structure and the intermediate structure are connected in a position near a second antinode of the longitudinal vibration of the waveguide rod, and a gain of a proximal side gain step is greater than a unit gain. The distal gain structure and the intermediate structure are connected in a position near a second last antinode of the longitudinal vibration of the waveguide rod, and a gain of a distal side gain step is less than the unit gain. The intermediate structure in the implementation manner comprises only one gain holding structure. One frequency adjustment structure exists on the gain holding structure. A gain of a front frequency modulation gain step of the frequency adjustment structure is less than the unit gain, and a gain of a rear frequency modulation gain step is greater than the unit gain.

[0031] FIG. **3** shows a waveguide rod for an ultrasonic scalpel according to a third implementation manner of this application and a waveform generated along the waveguide rod. The implementation manner comprises a proximal gain structure **1**, a distal gain structure **2**, an intermediate structure **3**, and a frequency adjustment structure **4**. The proximal gain structure is in a range of a first half wavelength of longitudinal vibration of the waveguide rod, and a most proximal gain step is near a first node of the longitudinal vibration. The distal gain structure is in a range of a last half wavelength of the longitudinal vibration of the waveguide rod, and a most distal gain step is near a last node of the longitudinal vibration. The proximal gain structure and the intermediate structure are connected in a position near a second antinode of the longitudinal vibration of the waveguide rod, and a gain of a proximal side gain step is greater than a unit gain. The distal gain structure and the intermediate structure are connected in a position near a second last antinode of the longitudinal vibration of the waveguide rod, and a gain of a distal side gain step is less than the unit gain. The intermediate structure in the implementation manner comprises three gain holding structures **31**, **32**, and **33**, a gain of a first intermediate gain step is less than the unit gain, and a gain of a second intermediate gain step is greater than the unit gain. One frequency adjustment structure **4** exists on the gain holding structure **32** in the middle. A gain of a front frequency modulation gain step of the frequency adjustment structure is greater than the unit gain, and a gain of a rear frequency modulation gain step is less than the unit gain.

[0032] FIG. **4** shows a waveguide rod for an ultrasonic scalpel according to a fourth implementation manner of this application and a waveform generated along the waveguide

rod. The implementation manner comprises a proximal gain structure **1**, a distal gain structure **2**, an intermediate structure **3**, and a frequency adjustment structure **4**. The proximal gain structure is a range of a first half wavelength of longitudinal vibration of the waveguide rod, and a most proximal gain step is near a first node of the longitudinal vibration. The distal gain structure is in a range of a last half wavelength of the longitudinal vibration of the waveguide rod, and a most distal gain step is near a last node of the longitudinal vibration. The proximal gain structure and the intermediate structure are connected in a position near a second antinode of the longitudinal vibration of the waveguide rod, and a gain of a proximal side gain step is greater than a unit gain. The distal gain structure and the intermediate structure are connected in a position near a second last antinode of the longitudinal vibration of the waveguide rod, and a gain of a distal side gain step is greater than the unit gain. The intermediate structure in the implementation manner comprises four gain holding structures **31**, **32**, **33**, and **34**, and a gain sequence of the intermediate gain steps is formed by alternately arranging a gain less than the unit gain and a gain greater than the unit gain. One frequency adjustment structure **4** exists on the second gain holding structure **32**. A gain of a front frequency modulation gain step of the frequency adjustment structure is greater than the unit gain, and a gain of a rear frequency modulation gain step is less than the unit gain.

[0033] FIG. **5** shows a waveguide rod for an ultrasonic scalpel according to a fifth implementation manner of this application and a waveform generated along the waveguide rod. The implementation manner comprises a proximal gain structure **1**, a distal gain structure **2**, an intermediate structure **3**, and a frequency adjustment structure **4**. The proximal gain structure is in a range of first two half wavelengths of longitudinal vibration of the waveguide rod, and a most proximal gain step is respectively near a first node and a second node of the longitudinal vibration. The distal gain structure is in a range of a last half wavelength of the longitudinal vibration of the waveguide rod, and a most distal gain step is near a last node of the longitudinal vibration. The proximal gain structure and the intermediate structure are connected in a position near a third antinode of the longitudinal vibration of the waveguide rod, and a gain of a proximal side gain step is greater than a unit gain. The distal gain structure and the intermediate structure are connected in a position near a second last antinode of the longitudinal vibration of the waveguide rod, and a gain of a distal side gain step is less than the unit gain. The intermediate structure in the implementation manner comprises only one gain holding structure. One frequency adjustment structure exists on the gain holding structure, a gain of a front frequency modulation gain step of the frequency adjustment structure is less than the unit gain, and a gain of a rear frequency modulation gain step is greater than the unit gain.

[0034] It should be noted that the gain steps in the examples of this application all have a stair form. However, the type of the gain steps is not limited in this application. Common gain step types such as a conical form, an exponential form, and a catenary form all fall within the protection scope of this application. In addition, the implementation solutions in FIG. **1** to FIG. **5** are only several relatively representative embodiments of this application. Persons skilled in the art may easily understand that the protection scope of this application is not merely limited to the ranges

defined in the implementation manners, and combinations, deformations, and changes made to the implementation manners all fall within the protection scope of this application.

1. A waveguide rod for an ultrasonic scalpel comprising:
a proximal gain structure;
a distal gain structure;
an intermediate structure; and
at least one frequency adjustment structure located on the intermediate structure, wherein
the proximal gain structure and the intermediate structure are connected at a position corresponding to an antinode of a longitudinal vibration of the waveguide rod through a proximal side gain step,
the distal gain structure and the intermediate structure are connected at a position near corresponding to an antinode of the longitudinal vibration of the waveguide rod through a distal side gain step,
the intermediate structure comprises N gain holding structures, and when N is greater than one, the gain holding structures are connected two by two in a position near an antinode of the longitudinal vibration of the waveguide rod through an intermediate gain step; and wherein
the frequency adjustment structure is disposed on the gain holding structure.

2. The waveguide rod according to claim **1**, wherein a gain of the proximal side gain step is one of greater than or less than a unit gain, and a distance between the proximal side gain step and the antinode is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod.

3. The waveguide rod according to claim **2**, wherein the proximal side gain step is located in a position of the antinode of the longitudinal vibration of the waveguide rod.

4. The waveguide rod according to claim **1**, wherein a gain of the distal side gain step is one of greater than or less than a unit gain, and a distance between the distal side gain step and the antinode is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod.

5. The waveguide rod according to claim **4**, wherein the distal side gain step is located at a position of the antinode of the longitudinal vibration of the waveguide rod.

6. The waveguide rod according to claim **1**, wherein the proximal gain structure is located in a range of a first half wavelength or a range of first two half wavelengths of the longitudinal vibration of the waveguide rod.

7. The waveguide rod according to claim **1**, wherein the distal gain structure is located in a range of a last half wavelength or a range of last two half wavelengths of the longitudinal vibration of the waveguide rod.

8. The waveguide rod according to claim **1**, wherein
one or more proximal gain steps are disposed at a position near a node of the longitudinal vibration of the waveguide rod on the proximal gain structure,
at most one proximal gain step is disposed at a position near each node,
a distance between the proximal gain step and the node is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod, and a gain of the proximal gain step is greater than a unit gain.

9. The waveguide rod according to claim **8**, wherein the proximal gain step is located at a position corresponding to a node of the longitudinal vibration of the waveguide rod.

10. The waveguide rod according to claim **1**, wherein one or more distal gain steps are disposed at a position near a node of the longitudinal vibration of the waveguide rod on the distal gain structure, at most one distal gain step is disposed at a position near each node, a distance between the distal gain step and the node is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod, and a gain of the distal gain step is greater than a unit gain.

11. The waveguide rod according to claim **10**, wherein the distal gain step is located at a position of a node of the longitudinal vibration of the waveguide rod.

12. The waveguide rod according to claim **1**, wherein a distance between each intermediate gain step and the anti-node of the longitudinal vibration of the waveguide rod is less than 5% of a half wavelength of the longitudinal vibration of the waveguide rod.

13. The waveguide rod according to claim **12**, wherein the intermediate gain step is located at a position of the antinode of the longitudinal vibration of the waveguide rod.

14. The waveguide rod according to claim **1**, wherein N is equal to 1.

15. The waveguide rod according to claim **1**, wherein N is an odd number greater than 1.

16. The waveguide rod according to claim **15**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is: a gain of each of a first intermediate gain step to an $((N-1)/2)$th intermediate gain step is greater than a unit gain, and a gain of each of an $((N-1)/2+1)$th intermediate gain step to an $(N-1)$th intermediate gain step is less than the unit gain.

17. The waveguide rod according to claim **15**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is: a gain of each of a first intermediate gain step to an $((N-1)/2)$th intermediate gain step is less than a unit gain, and a gain of each of an $((N-1)/2+1)$th intermediate gain step to an $(N-1)$th intermediate gain step is greater than the unit gain.

18. The waveguide rod according to claim **15**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain greater than a unit gain and a gain less than the unit gain.

19. The waveguide rod according to claim **15**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain less than a unit gain and a gain greater than the unit gain.

20. The waveguide rod according to claim **1**, wherein N is equal to 2.

21. The waveguide rod according to claim **20**, wherein a gain of an intermediate gain step connecting two gain holding structures is greater than a unit gain.

22. The waveguide rod according to claim **20**, wherein a gain of an intermediate gain step connecting two gain holding structures is less than a unit gain.

23. The waveguide rod according to claim **1**, wherein N is an even number greater than 2.

24. The waveguide rod according to claim **23**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain greater than a unit gain and a gain less than the unit gain.

25. The waveguide rod according to claim **23**, wherein a gain sequence of the intermediate gain steps connecting the gain holding structures is formed by sequentially and alternately arranging a gain less than a unit gain and a gain greater than the unit gain.

26. The waveguide rod according to claim **1**, wherein each frequency adjustment structure forms a front frequency modulation gain step and a rear frequency modulation gain step on a gain holding structure, only one node of the longitudinal vibration of the waveguide rod is disposed between the front frequency modulation gain step and the rear frequency modulation gain step, a distance between the front frequency modulation gain step and the rear frequency modulation gain step is less than a distance between two antinodes of the longitudinal vibration that are adjacent to a node, and one gain of the front frequency modulation gain step and the rear frequency modulation gain step is greater than a unit gain and the other gain is less than the unit gain.

27. The waveguide rod according to claim **26**, wherein the gain of the front frequency modulation gain step is less than the unit gain, and the gain of the rear frequency modulation gain step is greater than the unit gain.

28. The waveguide rod according to claim **26**, wherein the gain of the front frequency modulation gain step is greater than the unit gain, and the gain of the rear frequency modulation gain step is less than the unit gain.

* * * * *

专利名称(译)	超声波手术刀的波导棒		
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摘要(译)

具有相对理想的振幅和频率的超声手术刀的波导杆包括近端增益结构，远端增益结构，中间结构和频率调节结构。近端增益结构和中间结构通过近端侧增益台阶在波导杆的纵向振动的波腹附近的位置处连接。远端增益结构和中间结构通过远端侧增益台阶在波导杆的纵向振动的波腹附近的位置处连接。中间结构包括N个（N＞0，并且N是整数）增益保持结构，该增益保持结构通过中间增益台阶在波导棒的纵向振动的波腹附近的位置处被两个两个连接。 X（X＞0，并且X是整数）频率调整结构存在于增益保持结构上。波导杆提供了具有相对较大的叶片幅度的超声手术刀，并且还使得超声手术刀能够以稳定且合适的振动频率工作，从而超声手术刀可以有效地切割人体组织。
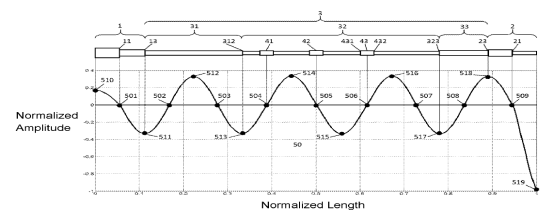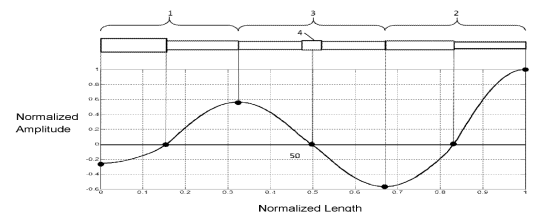

FIG. 1

FIG. 2