plasma generation gas. This may cause a molten thermal spray material to adhere to an inner surface (discharge surface) of the anode. In particular, depending on the properties of the thermal spray material, such as a specific gravity and particle size of the thermal spray material powder, the thermal spray material molten under the influence of the swirling gas flow is more likely to adhere to the discharge surface of the anode. Furthermore, in such conventional plasma torches, the thermal spray material has a low melting efficiency, and the thermal spray material may not be fully utilized for forming the film. It is noted that melting efficiency refers to the rate at which the molten thermal spray material is emitted from the plasma torch.

[0007]

Therefore, there is a need for a plasma torch that can suppress damage on the electrode while stably improving the melting efficiency of thermal spray material, in order to further improve the efficiency of forming films made of various thermal spray materials on the surface of substrates using plasma.

[0008]

Thus, a plasma torch e.g., as described in Patent Document 3 has been proposed. In the arrangement of the electrodes and magnets for generating plasma in the plasma torch described in Patent Document 3, a direction of rotation of the pole of discharge and a vector of the magnetic flux of the current and magnetic field that determine a magnitude of force are not orthogonal to each other. Therefore, a vector product of the current and the magnetic flux of the magnetic field becomes unstable, and the rotation direction of the pole point is reversed or the pole point does not rotate. As a result, there is a problem in that the poles become stuck and the heat becomes concentrated.

[0009]

Furthermore, in the plasma torch described in Patent Document 3, if the vector product of the current and the magnetic flux of the magnetic field is unstable, a thermal spray material introduction pipe (injector) that supplies thermal spray material into the discharge space momentarily becomes a discharge path, a discharge current flows into the thermal spray material introduction pipe, and there is a problem where the thermal spray material introduction pipe melts.

[PRIOR ART]

[0010]

[Patent Document]

[Patent Document 1] JP H8-319552 A
[Patent Document 2] JP 2011-071081 A
[Patent Document 3] JP 5799153 B

[Outline of the Invention]

[Problems to be solved by the invention]

[0011]

Embodiments of the present invention provide a plasma torch, a plasma thermal spraying device, and a method of controlling a plasma torch that are capable of stabilizing a rotation of the pole of discharge by maintaining an orthogonality of the vector product of a current for generating plasma and a magnetic flux of a magnetic field, which is also possible to suppress damage on a thermal spray material introduction tube.

[0012]

[Means for solving the problem]

According to a first aspect of the present invention, there is provided a plasma torch that rotates a generated plasma along a central axis, ejects the plasma in an axial direction, melts a powder of a thermal spraying material with the plasma, and expels the molten powder from the front nozzle opening to outside, where the plasma torch includes: a first electrode formed in a cylindrical shape having a first through hole extending in the axial direction at a center, the first electrode having a first discharge surface continuously formed around a front end of the first through hole; a second electrode formed in a cylindrical shape having a second through hole extending in the axial direction at a center and located on a front side of the first electrode, the second electrode having a second discharge surface continuously formed around a rear end of the second through hole so as to face the first discharge surface of the first electrode; a first magnet provided on a rear side of the first electrode opposite to the first discharge surface; a second magnet provided on an outer periphery of the second electrode; a third magnet provided on a front side of the second electrode opposite to the second discharge surface; a fourth magnet provided on an outer periphery of the first electrode and facing the second magnet in the axial direction; a thermal spray material introduction pipe slidably provided in the first through hole along the central axis, that supplies thermal spray material powder from a supply port to a discharge space formed between the first electrode and the second electrode; and a plasma generation gas supply passage that supplies plasma generation gas to the discharge space from the outer peripheral side of the first electrode, wherein a vector, of current flowing between the first discharge surface of the first electrode and the second discharge surface of the second electrode to generate the plasma, and a vector, of magnetic flux of a combined magnetic field by the first magnet, the second magnet, the third magnet, and the fourth magnet, are orthogonal.

[0013]

In an embodiment of the plasma torch, the first electrode is arranged as a mirror image of the second electrode with respect to a plane passing between the first electrode and the second electrode

and orthogonal to the central axis, and the first discharge surface of the first electrode is positioned as a mirror image of the second discharge surface of the second magnet with respect to the plane.

[0014]

In an embodiment of the plasma torch, the first magnet is arranged as a mirror image of the third magnet with respect to the plane, and the vector of magnetic flux of the magnetic field of the first magnet is positioned as a mirror image of the vector of magnetic flux of the magnetic field of the third magnet with respect to the plane.

[0015]

In an embodiment of the plasma torch, the second magnet is arranged as a mirror image of the fourth magnet with respect to the plane, and the vector of magnetic flux of the magnetic field of the second magnet is a mirror image of the vector of magnetic flux of the magnetic field of the fourth magnet with respect to the plane.

[0016]

In an embodiment of the plasma torch, the first magnet is arranged inside the first electrode in a region between the first through hole and the outer periphery, and the third magnet is arranged inside the second electrode in a region between the second through hole and the outer periphery.

[0017]

In an embodiment of the plasma torch, the fourth magnet is continuously formed so as to surround the front end of the first electrode, and the second magnet is continuously formed so as to surround the rear end of the second electrode.

[0018]

In an embodiment of the plasma torch, the first magnet has a cylindrical shape with a through hole extending in the axial direction centered on the central axis, the second magnet has a cylindrical shape with a through hole extending in the axial direction centered on the central axis, the third magnet has a cylindrical shape with a through hole extending in the axial direction centered on the central axis, and the fourth magnet has a cylindrical shape with a through hole extending in the axial direction centered on the central axis.

[0019]

In an embodiment of the plasma torch, the first discharge surface of the first electrode and the second discharge surface of the second electrode are inclined, such that a gap between the first discharge surface of the first electrode and the second discharge surface of the second electrode widens toward the central axis.

[0020]

In an embodiment of the plasma torch, a magnitude of the inclination of the first discharge surface with respect to the plane

orthogonal to the central axis is the same as a magnitude of the inclination of the second discharge surface with respect to the plane.

[0021]

In an embodiment of the plasma torch, the plasma generation gas supply passage supplies the plasma generation gas, from between the fourth magnet and the outer periphery of the first electrode, toward between the first discharge surface of the first electrode and the second discharge surface of the second electrode.

[0022]

In an embodiment, the plasma torch, further comprises a sheath gas supply passage that supplies sheath gas from the sheath gas supply port toward the discharge space from around the supply port of the thermal spray material introduction pipe.

[0023]

In an embodiment of the plasma torch, a plurality of the sheath gas supply ports of the sheath gas supply passage are provided at equal intervals, around the supply port of the thermal spray material introduction pipe.

[0024]

In an embodiment of the plasma torch, the sheath gas is the same gas as the plasma generation gas or a different gas from the plasma generation gas.

[0025]

In an embodiment of the plasma torch, the sheath gas is a gas containing one or more selected from a group containing noble gas elements, nitrogen, and hydrogen.

[0026]

In an embodiment of the plasma torch, a position of the supply port of the thermal spraying material introduction pipe is adjusted depending on the type of the thermal spraying material.

[0027]

In an embodiment of the plasma torch, the position of the supply port of the thermal spray material introduction pipe is adjusted so that the position of the supply port is within the discharge space.

[0028]

According to a second aspect of the present invention, there is provided a plasma thermal spraying device, including: the above plasma torch; a power source that applies a voltage between the first electrode and the second electrode; and a thermal spray material conveyance unit that conveys the thermal spray material to the thermal spray material introduction pipe.

[0029]

According to a third aspect of the present invention, there is provided a control method for a plasma torch, by using the above plasma torch, by sliding the thermal spraying material introduction pipe in the axial direction and adjusting the position of the supply

port of the thermal spraying material introduction pipe according to the type of the thermal spraying material, is provided to melt the powder of the thermal spray material.

[0030]
[Effect of the invention]

According to embodiments of the present invention, it is possible to maintain the orthogonality of the vector product of the current for generating plasma and the magnetic flux of the magnetic field, to stabilize the rotation of the pole of the discharge, and to suppress the consumption of the thermal spray material introduction pipe.

[Brief explanation of drawings]
[0031]
[FIG. 1] FIG. 1 is a diagram showing the configuration of a plasma torch according to an embodiment of the present invention.
[FIG. 2] FIG. 2 is a partially enlarged view of region Q of the plasma torch shown in FIG. 1.
[FIG. 3] FIG. 3 is a diagram showing the shape of the first magnet shown in FIG. 1.
[FIG. 4] FIG. 4 is a diagram showing an example of the temperature distribution of a plasma jet.
[FIG. 5] FIG. 5 is an explanatory diagram showing a state in which the plasma torch 11 shown in FIG. 1 generates plasma.
[FIG. 6] FIG. 6 is an explanatory diagram showing the state of magnetic flux of the plasma torch 11 shown in FIG. 1.
[FIG. 7A] FIG. 7A is a diagram showing an example of a positive electrode arrangement.
[FIG. 7B] FIG. 7B is a diagram showing an example of an electrode arrangement of opposite polarity.

[Mode for carrying out the invention]
[0032]

Hereinafter, modes for carrying out the present invention (hereinafter referred to as embodiments) will be described in detail based on the drawings. In this embodiment, a case where a plasma torch is applied to a plasma thermal spraying device will be described. It is noted that the present invention is not limited to the following embodiments. That is, the plasma torch according to the present invention can be applied to a wide variety of applications such as thermal spraying, melting, and gas heating. Furthermore, the constituent elements in the embodiments described below include those that can be easily assumed by those skilled in the art, and those that are substantially the same. Furthermore, the components disclosed in the embodiments below can be combined as appropriate.
[0033]
<Plasma thermal spraying device>