

DISC-SHAPED PERMANENT MAGNET EDDY CURRENT BRAKING DEVICE AND RAILWAY VEHICLE

[0001] The present application claims the priority to Chinese Patent Application No. 202310849377.3, titled "DISC-SHAPED PERMANENT MAGNET EDDY CURRENT BRAKING DEVICE AND RAILWAY VEHICLE", filed on July 11, 2023 with the China National Intellectual Property Administration, which is incorporated herein by reference in its entirety.

FIELD

[0002] The present application relates to the technical field of rail vehicles, and in particular to a disc-shaped permanent magnet eddy current braking device for a rail vehicle. The present application further relates to a rail vehicle provided with the disc-shaped permanent magnet eddy current braking device.

BACKGROUND

[0003] With the speed increase of multiple-unit trains, braking devices face severe challenges. Conventional friction braking is constrained by the thermal properties of friction materials. Excessively high speeds can cause increased wear and tear on brake discs and pads, reduced friction performance, and even phenomena such as thermal cracks in brake discs or failure of fasteners. Therefore, combining non-friction braking with friction braking technology is a reasonable configuration for high-speed multiple-unit trains.

[0004] The primary non-friction braking technologies include: resistive braking, regenerative braking, and eddy current braking. Resistive braking and regenerative braking cannot be applied onto trailer bogies having no traction motor, while eddy current braking has no such limitation.

[0005] Eddy current braking can be classified into two types: disc-shaped eddy current braking and linear eddy current braking. The principle of the eddy current braking is as follows: when a conductor cuts through magnetic field lines, it generates an induced current. Base on Lenz's law, the magnetic force (Ampere's force) acting on the induced current in the

conductor always opposes (or resists) the motion of the conductor. In other words, the magnetic field has a "repelling incoming, retaining outgoing" effect on the conductor.

[0006] Linear eddy current braking, similar to magnetic rail braking, involves lowering an electromagnet to a position a few millimeters above the rail surface without making contact with the rail. It utilizes the relative motion between the electromagnet and the rail to induce eddy currents in the rail, generating braking force that converts the kinetic energy of the trains into heat, which is then dissipated into the atmosphere through the rail. Linear eddy current braking has been applied onto Germany's ICE3 multiple-unit trains; however, rail temperature rise directly affects operational safety and interferes with rail signal transmission.

[0007] Disc-shaped eddy current braking involves mounting metal induction discs (brake discs) and magnetic field generation devices on the axles or output shafts of gearboxes. During braking, magnetic fields induce strong eddy currents on the rotating induction disc surfaces, generating braking force and converting the kinetic energy of the trains into heat, which is dissipated into the atmosphere. Disc-shaped eddy current braking has been applied onto Japan's 100-series and 300-series multiple-unit trains.

[0008] Most existing disc-shaped eddy current braking systems utilize electromagnets for excitation, where the magnitude and on/off control of the magnetic field are adjusted by the coil current. This method offers convenient control; however, practical research and applications have revealed a serious issue with electromagnetic eddy current braking, that is, the need for extremely large excitation coils and high currents, resulting in significant mass of the braking device. For example, a set of disc-shaped eddy current braking device used in Japan's 300-series multiple-unit trains weighs approximately one ton.

[0009] In conclusion, there is a need to develop the disc-shaped eddy current braking device that do not rely on electromagnet excitation, namely disc-shaped permanent magnet eddy current braking device.

SUMMARY

[0010] A main object of the present application is to provide a disc-shaped permanent magnet eddy current braking device. This device utilizes permanent magnets (stators) to generate a magnetic field that impedes the rotation of the brake disc (rotor). By using a driving motor to control the rotation of the stators, the eddy currents and braking force can be

activated and deactivated. This device can replace friction braking, thereby reducing wear on the friction pairs.

[0011] In order to achieve the above object, a disc-shaped permanent magnet eddy current braking device is provided according to the present application, including an axle, a brake disc mounted on the axle, and a permanent magnet eddy current braking device located on a side of the brake disc. The permanent magnet eddy current braking device includes an outer-ring permanent magnet assembly and an inner-ring permanent magnet assembly. The outer-ring permanent magnet assembly includes multiple outer-ring permanent magnets which are uniformly distributed in a circumferential direction, with S poles and N poles of the outer-ring permanent magnets being successively and alternately arranged. The inner-ring permanent magnet assembly includes multiple inner-ring permanent magnets which are uniformly distributed in the circumferential direction, with S poles and N poles of the inner-ring permanent magnets being successively and alternately arranged. The inner-ring permanent magnet assembly is rotatable with respect to the outer-ring permanent magnet assembly, so as to control a braking force by changing phases of the inner-ring permanent magnets.

[0012] Optionally, magnetic poles of both the outer-ring permanent magnets and the inner-ring permanent magnets are perpendicular to a disc surface of the brake disc.

[0013] Optionally, magnetic yokes are respectively provided at ends of the outer-ring permanent magnets and the inner-ring permanent magnets facing the brake disc.

[0014] Optionally, the disc-shaped permanent magnet eddy current braking device further includes pole pieces corresponding to the outer-ring permanent magnets and the inner-ring permanent magnets, where the pole pieces have same phase as the outer-ring permanent magnets.

[0015] Optionally, springs are provided at ends of the outer-ring permanent magnets and the inner-ring permanent magnets that are away from the brake disc, so as to keep the outer-ring permanent magnets and the inner-ring permanent magnets in full contact with the corresponding magnetic yokes and pole pieces through elastic force.

[0016] Optionally, the outer-ring permanent magnet assembly and the inner-ring permanent magnet assembly are mounted inside a support housing, which is connected to a frame via

linkages and rotatably engaged with the axle through bearings.

[0017] Optionally, the outer-ring permanent magnet assembly and the inner-ring permanent magnet assembly are mounted inside the support housing via two parallel mounting discs, with multiple outer-ring mounting bases provided on the mounting discs. The outer-ring permanent magnets and the magnetic yokes are located inside the outer-ring mounting bases, while the inner-ring permanent magnets and the magnetic yokes are located in slots of an inner-ring rotating disc, which is rotatable relative to the mounting discs.

[0018] Optionally, the pole pieces are fixed on a side of the support housing adjacent to the brake disc.

[0019] Optionally, a driving motor is provided inside the support housing. The inner-ring rotating disc is provided with a gear ring. The driving motor is engaged with the gear ring through gears to drive the inner-ring rotating disc to rotate.

[0020] In order to achieve another object, a rail vehicle is provided according to the present application, including a vehicle body, a framework, and a braking device. The braking device is the disc-shaped permanent magnet eddy current braking device as described in any of the preceding technical solutions.

[0021] The disc-shaped permanent magnet eddy current braking device provided according to the present application employs permanent magnet technology, addressing the issue of excessive stator coil weight in conventional disc-shaped eddy current braking devices and better meeting practical application requirements. As a non-friction braking technology, it eliminates wear on friction pairs, brake dust, and noise pollution. Furthermore, by utilizing permanent magnets to generate the magnetic field, and eliminates the need for external excitation power supplies and excitation windings, significantly reducing power consumption and copper usage in braking, as well as lowering the weight of the eddy current braking device. This achieves lightweight and compact design of the eddy current braking device while maintaining stable and durable braking force, avoiding the risk of braking failure during power outages, and offering higher reliability. Compared to air braking, the braking force is applied more linearly, reducing longitudinal impact during train braking and enhancing passenger comfort.

[0022] The rail vehicle provided according to the present application is provided with the

aforementioned disc-shaped permanent magnet eddy current braking device. Given the technical advantages of this braking device, the rail vehicle including it also exhibits corresponding technical benefits.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a schematic view illustrating a braking principle of a disc-shaped permanent magnet eddy current braking device provided according to an embodiment of the present application;

10 [0024] FIG. 2 is a schematic view showing generation of eddy currents in a brake disc depicted in FIG. 1;

[0025] FIG. 3 is a partial schematic view illustrating opposite magnetic poles of inner-ring and outer-ring permanent magnets in a same phase when no braking force is applied;

[0026] FIG. 4 is a longitudinal sectional view of FIG. 3;

15 [0027] FIG. 5 is a partial schematic view showing consistent magnetic poles of inner-ring and outer-ring permanent magnets in a same phase when a braking force is applied;

[0028] FIG. 6 is a longitudinal sectional view of FIG. 5;

[0029] FIG. 7 is a schematic structural view of a disc-shaped permanent magnet eddy current braking device provided according to an embodiment of the present application;

20 [0030] FIG. 8 is a schematic view illustrating magnetic pole distribution of the disc-shaped permanent magnet eddy current braking device shown in FIG. 7 when in a braking state;

[0031] FIG. 9 is a schematic view illustrating magnetic pole distribution of the disc-shaped permanent magnet eddy current braking device shown in FIG. 7 when in a moving state.

[0032] Reference numerals in the drawings are as follows:

25 10 brake disc; 20 eddy current; 30 outer-ring permanent magnet assembly; 31 outer-ring permanent magnet; 32 outer-ring mounting base; 33 outer-ring magnetic yoke; 40 inner-ring permanent magnet assembly; 41 inner-ring permanent magnet; 42 inner-ring rotating disc; 43 inner-ring magnetic yoke; 50 spring; 60 pole piece; 70 axle; 80 support housing; 90 bearing; 110 first mounting disc; 120 second mounting disc; 130 driving motor; 140 gear; 150 positioning pin.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0033] To enable those skilled in the art to better understand the solutions of the present application, the present application is further described in detail hereinafter in conjunction with the accompanying drawings and embodiments.

[0034] In this specification, the terms "up, down, inner, outer" are established based on the positional relationship shown in the attached drawings, and the corresponding positional relationship may vary with different attached drawings. Therefore, those terms should not be construed as an absolute limitation of the scope of protection. Moreover, the relationship terminologies such as "first", "second", and the like are only used herein to distinguish one element from another having the same name, rather than to necessitate or imply that the actual relationship or order exists between the elements.

[0035] References are made to FIGS. 1 and 2. FIG. 1 is a schematic view illustrating a braking principle of a disc-shaped permanent magnet eddy current braking device provided according to an embodiment of the present application. FIG. 2 is a schematic view showing generation of eddy currents in a brake disc depicted in FIG. 1.

[0036] The braking principle of the disc-shaped permanent magnet eddy current braking device provided according to the present application is as follows.

[0037] On one side of the brake disc, permanent magnets are arranged alternately in the order of S-pole and N-pole (or N-pole and S-pole) in the direction of rotation. When these magnets are brought close to the brake disc, eddy currents are generated on the surface of the brake disc. Since these eddy currents produce a magnetic field, Lorentz forces act in a direction that opposes the rotation of the brake disc, resulting in braking force on the brake disc. Given that the electrical resistance of the brake disc is very low, the generated eddy currents are of high intensity. The strong currents cutting through magnetic field lines produce substantial Lorentz forces, enabling the rotary permanent magnet eddy current braking device to generate significant braking force.

[0038] References are made to FIGS. 3 to 6. FIG. 3 is a partial schematic view illustrating opposite magnetic poles of inner-ring and outer-ring permanent magnets in a same phase when no braking force is applied. FIG. 4 is a longitudinal sectional view of FIG. 3. FIG. 5 is a

partial schematic view showing consistent magnetic poles of inner-ring and outer-ring permanent magnets in a same phase when a braking force is applied. FIG. 6 is a longitudinal sectional view of FIG. 5.

[0039] In the disc-shaped permanent magnet eddy current braking device provided according to the present application, the permanent magnets are arranged in two groups: an outer-ring permanent magnet assembly 30 and an inner-ring permanent magnet assembly 40. The outer-ring permanent magnet assembly 30 includes multiple outer-ring permanent magnets 31 evenly distributed in a circumferential direction, with S-poles and N-poles of the outer-ring permanent magnets 31 arranged alternately. The inner-ring permanent magnet assembly 40 includes multiple inner-ring permanent magnets 41 evenly distributed in the circumferential direction, with S-poles and N-poles of the inner-ring permanent magnet assembly 40 arranged alternately. The outer-ring permanent magnet assembly 30 is fixed, while the inner-ring permanent magnet assembly 40 is rotatable (in the circumferential direction) relative to the outer-ring permanent magnet assembly 30 by at least the distance of one pair of magnetic poles, which alters the magnetic pole correspondence between the inner-ring permanent magnets 41 and the outer-ring permanent magnets 31, allowing the magnetic poles of the inner-ring permanent magnets 41 and the outer-ring permanent magnets 31 in the same phase to either align or oppose each other, and enabling transitions and adjustments between these two states.

[0040] During normal train operation, the magnetic poles of the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41 in the same phase are opposite. The magnetic field forms a closed loop through pole pieces 60 without passing through the brake disc 10, preventing the generation of eddy currents in the brake disc 10 and thus eliminating braking force on the brake disc 10.

[0041] During train braking, a power-driven device (e.g., a motor) rotates the inner-ring permanent magnets 41, aligning the magnetic poles of the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41 in the same phase. The magnetic field then passes through the pole pieces 60, forming a closed loop in the brake disc 10. This creates a magnetic field in the brake disc 10, which, along with the rotation of the brake disc 10, generates eddy currents and subsequently braking force. In this state, the braking force reaches 100%.

[0042] In the state shown in FIGS. 3 and 4, the braking force is 0%, while in the state shown

in FIGS. 5 and 6, the braking force is 100%. Continuous rotation of the inner-ring permanent magnets 41 theoretically allows for continuous adjustment of braking force, thereby achieving stepless regulation. In other words, the braking force can be adjusted between 0% and 100%.

[0043] References are further made to FIG 7, which is a schematic structural view of a disc-shaped permanent magnet eddy current braking device provided according to an embodiment of the present application.

[0044] In a specific embodiment, the disc-shaped permanent magnet eddy current braking device provided according to the present application mainly includes a brake disc 10, an axle 70, and a permanent magnet eddy current braking device. The brake disc 10 is mounted on the axle 70, and the permanent magnet eddy current braking device is located on one side of the brake disc 10. The permanent magnet eddy current braking device includes an outer-ring permanent magnet assembly 30 and an inner-ring permanent magnet assembly 40.

[0045] The outer-ring permanent magnet assembly 30 and the inner-ring permanent magnet assembly 40 are mounted in a support housing 80. The support housing 80 is connected to the vehicle frame via linkages and rotates in coordination with the axle 70 through a bearing 90, ensuring that the support housing 80 remains relatively stationary during vehicle operation.

[0046] Specifically, the outer-ring permanent magnet assembly 30 and the inner-ring permanent magnet assembly 40 are mounted inside the support housing 80 through a first mounting disc 110 and a second mounting disc 120 parallel to each other. The first mounting disc 110 and the second mounting disc 120 are provided with outer-ring mounting bases 32. The outer-ring permanent magnets 31 and outer-ring magnetic yokes 33 of the outer-ring permanent magnet assembly 30 are placed inside these outer-ring mounting bases 32. The inner-ring permanent magnets 41 and inner-ring magnetic yokes 43 of the inner-ring permanent magnet assembly 40 are positioned in slots in the inner-ring rotating disc 42, which is rotatable relative to the first mounting disc 110 and the second mounting disc 120.

[0047] The inner-ring rotating disc 42 has a cross-sectional shape similar to that of the outer-ring mounting bases 32, with the key difference being that the outer-ring mounting bases 32 include multiple individually distributed components arranged circumferentially, while the inner-ring rotating disc 42 is an integrated component capable of circumferential rotation.

[0048] The magnetic poles of both the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41 are perpendicular to the surface of the brake disc 10. Rare-earth permanent magnets, such as Nd-Fe-B, which exhibit high magnetic energy product and high coercivity, can be selected to continuously generate a strong magnetic field without the need for current excitation.

[0049] The ends of the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41 facing the brake disc are provided with outer-ring magnetic yokes 33 and inner-ring magnetic yokes 43, respectively. The outer-ring magnetic yokes 33 and the inner-ring magnetic yokes 43 do not generate magnetic fields themselves but serve to transmit and confine magnetic flux lines in the magnetic circuit, preventing their dispersion and concentrating the flux lines to enhance the efficiency of the system.

[0050] In this embodiment, there are twelve sets of outer-ring permanent magnets 31 and outer-ring magnetic yokes 33, evenly distributed every 30 degrees along the circumference and placed in twelve outer-ring mounting bases 32. These outer-ring mounting bases 32 are secured inside the support housing 80 via the first mounting disc 110 and the second mounting disc 120. Similarly, there are twelve sets of inner-ring permanent magnets 41 and inner-ring magnetic yokes 43, evenly distributed at 30 degrees intervals along the circumference and placed in twelve slots in the inner-ring rotating disc 42.

[0051] Certainly, the inner-ring permanent magnets 41 and the inner-ring magnetic yokes 43 could also be mounted inside the support housing 80 through separately provided third and fourth mounting discs.

[0052] The pole pieces 60 correspond to the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41, sharing the same phase as the outer-ring permanent magnets 31. There are twelve sets of pole pieces 60, evenly distributed every 30 degrees along the circumference. These pole pieces 60 are fixed to the side of the support housing 80 adjacent to the brake disc 10, presenting a small gap from the brake disc 10. The pole pieces 60 are made of materials with good magnetic permeability to effectively transmit magnetic flux lines.

[0053] Pre-compressed springs 50 are mounted at the ends of the outer-ring permanent magnets 31 and the inner-ring permanent magnets 41 away from the brake disc 10. These springs apply elastic force to ensure full contact between the permanent magnets, their

corresponding magnetic yokes, and the pole pieces 60. After mounting in place, the outer-ring magnetic yokes 33 are positioned and secured through positioning pins 150 relative to the outer-ring mounting bases 32.

[0054] A driving motor 130 is mounted inside the support housing 80. The inner-ring rotating disc 42 is provided with a gear ring. The driving motor 130 is engaged with the gear ring through a gear 140, enabling the rotation of the inner-ring rotating disc 42 and, consequently, altering the phase of the inner-ring permanent magnets 41 to control the braking force.

[0055] References are made to FIGS. 8 and 9. FIG. 8 is a schematic view illustrating magnetic pole distribution of the disc-shaped permanent magnet eddy current braking device shown in FIG. 7 when in a braking state. FIG. 9 is a schematic view illustrating the magnetic pole distribution when the disc-shaped permanent magnet eddy current braking device is in a moving state.

[0056] In the braking state, the motor 130 drives the rotation of the inner-ring rotating disc 42. When the magnetic poles of the inner-ring permanent magnets 41 and the outer-ring permanent magnets 31 in the same phase align with each other, the magnetic field forms a closed loop through the pole pieces 60 and the brake disc 10. As the brake disc 10 rotates, eddy currents are generated within the brake disc 10, producing braking force.

[0057] During normal operation, the motor 130 again drives the rotation of the inner-ring rotating disc 42, causing the magnetic poles of the inner-ring permanent magnets 41 and the outer-ring permanent magnets 31 in the same phase to oppose each other. The magnetic field forms a closed loop through the pole pieces 60 without passing through the brake disc 10, reducing the braking force to zero.

[0058] The above embodiments are only preferred solutions of the present application, and the present application is not specifically limited thereto. On this basis, targeted adjustments can be made according to actual needs, thereby obtaining different embodiments. For example, the outer-ring permanent magnet assembly 30 and the inner-ring permanent magnet assembly 40 could be mounted inside the support housing 80 by means of alternative methods, or the inner-ring rotating disc 42 could be driven to rotate via other means. Given the numerous possible implementations, no further examples are provided here.

[0059] This disc-shaped permanent magnet eddy current braking device utilizes a combination of permanent magnets, magnetic yokes, and pole pieces to generate and transmit magnetic fields. The outer-ring permanent magnets 31 remain fixed, while the inner-ring permanent magnets 41 are rotated by the motor 130 to control the activation and deactivation of braking force. The permanent magnets generates magnetic field, eliminating the need for excitation coils, and achieving a lightweight and compact braking device. Additionally, the rotary eddy current braking method avoids the impact on tracks associated with linear eddy current braking and eliminates longitudinal shocks compared to air braking.

[0060] In addition to the aforementioned disc-shaped permanent magnet eddy current braking device, a rail vehicle is further provided according to the present application, including a vehicle body, a frame, and a braking device. The braking device is the disc-shaped permanent magnet eddy current braking device described above. For further details on the remaining structures of the rail vehicle, please refer to existing technologies, which are not elaborated upon here.

[0061] The principle and the embodiments of the present application are illustrated herein by specific examples. The above description of the embodiments is only intended to facilitate the understanding of the core concept of the present application. Those skilled in the art may make improvements and modifications to these embodiments of the present application without departing from the principle of the present application, and these improvements and modifications also fall within a scope of the claims of the present application.

CLAIMS

1. A disc-shaped permanent magnet eddy current braking device, comprising an axle (70), a brake disc (10) mounted on the axle (70), and a permanent magnet eddy current braking device located on one side of the brake disc (10); wherein

the permanent magnet eddy current braking device comprises an outer-ring permanent magnet assembly (30) and an inner-ring permanent magnet assembly (40), the outer-ring permanent magnet assembly (30) comprises a plurality of outer-ring permanent magnets (31) evenly distributed in a circumferential direction, with S-poles and N-poles of the outer-ring permanent magnets (31) arranged alternately in sequence, the inner-ring permanent magnet assembly (40) comprises a plurality of inner-ring permanent magnets (41) evenly distributed in the circumferential direction, with S-poles and N-poles of the inner-ring permanent magnets (41) arranged alternately in sequence, and the inner-ring permanent magnet assembly (40) is rotatable relative to the outer-ring permanent magnet assembly (30) to control a braking force by altering phase of the inner-ring permanent magnets (41).

2. The disc-shaped permanent magnet eddy current braking device according to claim 1, wherein magnetic poles of the outer-ring permanent magnets (31) and the inner-ring permanent magnets (41) are both perpendicular to a surface of the brake disc (10).

3. The disc-shaped permanent magnet eddy current braking device according to claim 2, wherein magnetic yokes are provided at ends of the outer-ring permanent magnets (31) and the inner-ring permanent magnets (41) facing the brake disc (10), respectively.

4. The disc-shaped permanent magnet eddy current braking device according to claim 3, further comprising pole pieces (60) corresponding to the outer-ring permanent magnets (31) and the inner-ring permanent magnets (41), wherein the pole pieces (60) have same phase as the outer-ring permanent magnets (31).

5. The disc-shaped permanent magnet eddy current braking device according to claim 4, wherein springs (50) are provided at ends of the outer-ring permanent magnets (31) and the inner-ring permanent magnets (41) away from the brake disc (10) to maintain full contact between the outer-ring permanent magnets (31) and the inner-ring permanent magnets (41) and their corresponding magnetic yokes and pole pieces (60) through elastic force.

6. The disc-shaped permanent magnet eddy current braking device according to claim 5, wherein the outer-ring permanent magnet assembly (30) and the inner-ring permanent magnet assembly (40) are mounted inside a support housing (80), which is connected to a frame via linkages and rotates in coordination with the axle (70) through bearings (90).

7. The disc-shaped permanent magnet eddy current braking device according to claim 6, wherein the outer-ring permanent magnet assembly (30) and the inner-ring permanent magnet assembly (40) are mounted inside the support housing (80) through two parallel mounting discs, with a plurality of outer-ring mounting bases (32) provided on the mounting discs; and

the outer-ring permanent magnets (31) and the magnetic yokes are located inside the plurality of outer-ring mounting bases (32), while the inner-ring permanent magnets (41) and the magnetic yokes are located in slots in an inner-ring rotating disc (42), which is rotatable relative to the mounting discs.

8. The disc-shaped permanent magnet eddy current braking device according to claim 7, wherein the pole pieces (60) are fixed to a side of the support housing (80) adjacent to the brake disc (10).

9. The disc-shaped permanent magnet eddy current braking device according to claim 7 or 8, wherein a driving motor (130) is provided inside the support housing (80), and the inner-ring rotating disc (42) is provided with a gear ring, with the driving motor (130) being engaged with the gear ring via a gear (140) to drive the inner-ring rotating disc (42) to rotate.

10. A rail vehicle, comprising a vehicle body, a frame, and a braking device, which is the disc-shaped permanent magnet eddy current braking device according to any one of claims 1 to 9.