PROPULSION CONTROL METHOD FOR ACTIVE ARTICULATION TUNNEL BORING MACHINE, CONTROLLER, AND CONTROL SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present disclosure is based on and claims priority of Chinese application for invention No. 202410054506.4, filed on January 15, 2024, the disclosure of which is hereby incorporated into this disclosure by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to the field of tunnel construction, particularly to a propulsion control method, a controller, and a control system for an actively articulated tunnel boring machine.

BACKGROUND

[0003] Tunnel boring machine (TBM) is the primary equipment for tunnel construction. With major global TBM design and development enterprises investing in equipment upgrades and construction efficiency improvements, TBMs are evolving towards automation, intelligence, greater depth, larger cross-sections, and longer distances. Tunnel boring machines can be classified into non-articulated, passively articulated, and actively articulated types based on their articulation forms, where actively articulated tunnel boring machines are widely used due to their small turning radius. Currently, in addition to standard construction procedures such as advancing, stopping, and segment assembly, tunnel boring machines can achieve simultaneous advancement and segment assembly by retracting and deactivating a portion of their propulsion cylinders. This method, known as continuous mining mode, is employed to improve construction efficiency.

DISCLOSURE OF THE INVENTION

[0004] According to one aspect of the present disclosure, there is provided a propulsion control method for an actively articulated tunnel boring machine, including: obtaining an actual position of the actively articulated tunnel boring machine, a designed axis, and a segment uplift amount; calculating a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount; and adjusting at least one of an actual correction torque of a propulsion system or an actual articulation angle of an articulation system of the actively articulated tunnel boring machine to match the actual position of the actively articulated tunnel boring machine with the planned tunneling trajectory.

[0005] In some embodiments, obtaining a clearance between a shield tail of the actively articulated tunnel boring machine and a segment in a predetermined direction; and adjusting the planned tunneling trajectory in a case where the clearance in the predetermined direction is less than a clearance threshold and the actively articulated tunnel boring machine is excavating in the predetermined direction.

deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the actively articulated tunnel boring machine, as well as a second trajectory deviation, a second deviation speed, and a second deviation acceleration corresponding to an end position of the actively articulated tunnel boring machine, where the second trajectory deviation is determined based on the segment uplift amount and a curvature of the designed axis; constructing a trajectory deviation polynomial between the planned tunneling trajectory and the designed axis based on a driving position and the initial position of the actively articulated tunnel boring machine; solving, based on the first trajectory deviation, the first deviation speed, the first deviation acceleration, the second trajectory deviation, the second deviation speed, and the second deviation acceleration, the trajectory deviation polynomial to obtain values of unknown constants of the trajectory deviation polynomial; obtaining a trajectory deviation corresponding to the actual position using the trajectory deviation polynomial; and obtaining the planned tunneling trajectory based on the trajectory deviation; adjusting the planned tunneling trajectory includes: using a trajectory deviation corresponding to the current position as the second trajectory deviation during the calculation of the planned tunneling trajectory.

[0017] In some embodiments, obtaining a current working mode of the actively articulated tunnel boring machine, which includes an advance mode or a continuous mining mode, where adjusting the actual correction torque includes: adjusting the actual correction torque by adjusting a propulsion cylinder state of the propulsion system according to the current working mode.

[0018] In some embodiments, calculating an actual propulsion speed of the actively articulated tunnel boring machine; and controlling the actual propulsion speed to match a target propulsion speed.

[0019] In some embodiments, calculating an actual total thrust of the actively articulated tunnel boring machine; and controlling the actual total thrust to match the target total thrust.

[0020] According to another aspect of the present disclosure, there is provided a controller for an actively articulated tunnel boring machine, including: a data obtaining module configured to obtain an actual position of the actively articulated tunnel boring machine, a designed axis, and a segment uplift amount; a data processing module configured to calculate a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount; and a control module configured to adjust at least one of an actual correction torque of a propulsion system or an actual articulation angle of an articulation system of the actively articulated tunnel boring machine to match the actual position of the actively articulated tunnel boring machine with the planned tunneling trajectory.

[0021] In some embodiments, the data obtaining module is further configured to obtain a clearance between a shield tail of the actively articulated tunnel boring machine and a segment in a predetermined direction; and the data processing module is further configured to adjust the planned tunneling trajectory in a case where the clearance in the predetermined direction is less than a clearance threshold and the actively articulated tunnel boring machine is excavating in the predetermined direction.

[0022] According to another aspect of the present disclosure, there is provided a controller for an actively articulated tunnel boring machine, including: a memory; and a processor coupled to the memory, the processor is configured to perform the aforementioned propulsion control method based on instructions stored in the memory.

[0023] According to another aspect of the present disclosure, there is provided a control system for an actively articulated tunnel boring machine, including: the controller described above; a guidance measurement module

[00111] In the above embodiment, by adjusting and stabilizing the actual articulation angle to achieve the target articulation angle, the actual tunneling trajectory is kept within an allowable range of the planned trajectory. This reduces the safety risks associated with maintaining the designed axis during tunnel turns or in the presence of segment uplift, and addresses the issue of unstable correction effects in resultant force point control schemes when the total propulsion thrust changes.

[00112] Figure 6 is a flowchart of a propulsion control method for an actively articulated tunnel boring machine according to other embodiments of the present disclosure.

[00113] In step 610, a planned attitude corresponding to the actual position on the planned tunneling trajectory is calculated, based on the actual position of the actively articulated tunnel boring machine.

[00114] In step 620, the first target correction torque is adjusted to obtain the third target correction torque, and the first target articulation angle is adjusted to obtain the third target articulation angle, based on the attitude deviation between the actual attitude of the actively articulated tunnel boring machine and the planned attitude.

[00115] In some embodiments, the first target correction torque, the first target articulation angle, and the attitude deviation are input into the adjustment model to obtain a second correction torque adjustment amount and a second articulation angle adjustment amount; and the first target correction torque is adjusted to obtain the third target correction torque using the second correction torque adjustment amount, and the first target articulation angle is adjusted using the second articulation angle adjustment amount to obtain the third target articulation angle.

[00116] In some embodiments, sample correction torques, sample articulation angles, and sample attitude deviations are obtained; and a machine learning model is trained to obtain a trained adjustment model, using the sample correction torques, the sample articulation angles and the sample attitude deviations as training data, with sample correction torque adjustment amounts and sample articulation angle adjustment amounts as label values.

[00117] By inputting the error between an actual horizontal attitude and a planned horizontal attitude, as well as the error between an actual vertical attitude and a planned vertical attitude, into the trained adjustment model, a second correction torque adjustment amount and a second articulation angle adjustment amount can be obtained. The second correction torque adjustment amount is added to a first target correction torque to yield a third target correction torque. The second target articulation angle is added to a first target articulation angle to obtain a third target articulation angle.

[00118] In step 630, the actual correction torque is adjusted to match the actual correction torque with the third target correction torque, and the actual articulation angle is adjusted to match the actual articulation angle with the third target articulation angle.

[00119] In the above embodiment, by adjusting and stabilizing the actual correction torque to achieve a target correction torque and the actual articulation angle to achieve a target articulation angle, the actual tunneling trajectory is kept within an allowable range of the planned trajectory. This reduces the safety risks associated with maintaining the designed axis during tunnel turns or in the presence of segment uplift, and addresses the issue of unstable correction effects in resultant force point control schemes when the total propulsion thrust changes.

[00120] In some embodiments, the current working mode of the tunnel boring machine is obtained, which includes an advance mode or a continuous mining mode. Based on the current working mode, the propulsion cylinder state of the propulsion system is adjusted to adjust the actual correction torque.

[00132] The data obtaining module 710 is configured to obtain an actual position of the actively articulated tunnel boring machine, a designed axis, and a segment uplift amount.

[00133] In some embodiments, the data obtaining module 710 is further configured to obtain a clearance between a shield tail of the actively articulated tunnel boring machine and a segment in a predetermined direction. The clearance in a predetermined direction includes, for example, a clearance between the right side of the shield tail and the segment, a clearance between the left side of the shield tail and the segment, a clearance between the upper side of the shield tail and the segment, and a clearance between the lower side of the shield tail and the segment.

[00134] In some embodiments, the data obtaining module 710 is further configured to obtain a current working mode of the actively articulated tunnel boring machine, the current working mode including an advance mode or a continuous mining mode.

[00135] The data processing module 720 is configured to calculate a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount.

[00136] In some embodiments, within tunnel turns, the planned tunneling trajectory is located on an inner side of designed axis bends. Under conditions of segment uplift, the planned tunneling trajectory is positioned below the designed axis.

[00137] In some embodiments, the data processing module 720 obtains a first trajectory deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the actively articulated tunnel boring machine, as well as a second trajectory deviation, a second deviation speed, and a second deviation acceleration corresponding to an end position of the actively articulated tunnel boring machine, where the second trajectory deviation is determined based on the segment uplift amount and a curvature of the designed axis; constructs a trajectory deviation polynomial between the planned tunneling trajectory and the designed axis based on a driving position and the initial position of the actively articulated tunnel boring machine; solves the trajectory deviation polynomial to obtain values of unknown constants of the trajectory deviation polynomial based on the first trajectory deviation, the first deviation speed, the first deviation acceleration, the second trajectory deviation, the second deviation speed, and the second deviation acceleration; obtains a trajectory deviation corresponding to the actual position using the trajectory deviation polynomial; obtains the planned tunneling trajectory based on the trajectory deviation.

[00138] In some embodiments, the data processing module 720 is further configured to adjust the planned tunneling trajectory in a case where the clearance in the predetermined direction is less than a clearance threshold and the actively articulated tunnel boring machine is excavating in the predetermined direction. For example, the trajectory deviation corresponding to the current position is used as the second trajectory deviation during the calculation of the planned tunneling trajectory. Real-time monitoring of the shield tail clearance can prevent damage to the segments and enhance operational safety.

[00139] The control module 730 is configured to adjust at least one of the actual correction torque of the propulsion system or the actual articulation angle of the articulation system of the actively articulated tunnel boring machine, to match the actual position of the actively articulated tunnel boring machine with the planned tunneling trajectory.

[00140] In some embodiments, the control module 730 adjusts a first target correction torque of the propulsion system to obtain a second target correction torque in a case where there is a deviation between the actual position

What is claimed is:

1. A propulsion control method for an actively articulated tunnel boring machine, comprising:

obtaining an actual position of the actively articulated tunnel boring machine, a designed axis, and a segment uplift amount;

calculating a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount; and

adjusting at least one of an actual correction torque of a propulsion system or an actual articulation angle of an articulation system of the actively articulated tunnel boring machine to match the actual position of the actively articulated tunnel boring machine with the planned tunneling trajectory.

2. The propulsion control method according to claim 1, further comprising:

obtaining a clearance between a shield tail of the actively articulated tunnel boring machine and a segment in a predetermined direction; and

adjusting the planned tunneling trajectory in a case where the clearance in the predetermined direction is less than a clearance threshold and the actively articulated tunnel boring machine is excavating in the predetermined direction.

3. The propulsion control method according to claim 1 or 2, wherein adjusting at least one of the actual correction torque of the propulsion system or the actual articulation angle of the articulation system of the actively articulated tunnel boring machine comprises:

adjusting a first target correction torque of the propulsion system to obtain a second target correction torque in a case where there is a deviation between the actual position of the actively articulated tunnel boring machine and the planned tunneling trajectory; and

adjusting the actual correction torque to match the actual correction torque with the second target correction torque;

optionally, adjusting the first target correction torque of the propulsion system to obtain the second target correction torque comprises:

calculating, based on the actual position of the actively articulated tunnel boring machine, a planned attitude corresponding to the actual position on the planned tunneling trajectory; and

adjusting, based on an attitude deviation between an actual attitude of the actively articulated tunnel boring machine and the planned attitude, the first target correction torque to obtain the second target correction torque;

optionally, the propulsion control method future comprising:

obtaining sample correction torques and sample attitude deviations; and

training a machine learning model, using the sample correction torques and the sample attitude deviations as training data, with sample correction torque adjustment amounts as label values, to obtain a trained correction torque adjustment model, wherein adjusting, based on the attitude deviation between the actual attitude of the tunnel boring machine and the planned attitude, the first target correction torque to obtain the second target correction torque comprises:

obtaining a first correction torque adjustment amount by inputting the first target correction torque and the attitude deviation into the correction torque adjustment model; and

adjusting the first target correction torque using the first correction torque adjustment amount to obtain the second target correction torque.

4. The propulsion control method according to claim 1 or 3, wherein adjusting at least one of the actual correction torque of the propulsion system or the actual articulation angle of the articulation system of the actively articulated tunnel boring machine comprises:

adjusting a first target articulation angle of the articulation system to obtain a second target articulation angle in a case where there is a deviation between the actual position of the actively articulated tunnel boring machine and the planned tunneling trajectory; and

adjusting the actual articulation angle to match the actual articulation angle with the second target articulation angle;

optionally, adjusting the first target articulation angle of the articulation system to obtain the second target articulation angle comprises:

calculating, based on the actual position of the actively articulated tunnel boring machine, a planned attitude corresponding to the actual position on the planned tunneling trajectory; and

adjusting, based on the attitude deviation between the actual attitude of the actively articulated tunnel boring machine and the planned attitude, the first target articulation angle to obtain the second target articulation angle;

optionally, the propulsion control method further comprising:

obtaining sample articulation angles and sample attitude deviations; and

training a machine learning model, using the sample articulation angles and the sample attitude deviations as training data, with sample articulation angle adjustment amounts as label values, to obtain a trained articulation angle adjustment model, wherein adjusting, based on the attitude deviation between the actual attitude of the actively articulated tunnel boring machine and the planned attitude, the first target articulation angle to obtain the second target articulation angle comprises:

obtaining a first articulation angle adjustment amount by inputting the first target articulation angle and the attitude deviation into the articulation angle adjustment model; and

adjusting the first target articulation angle using the first articulation angle adjustment amount to obtain the second target articulation angle.

5. The propulsion control method according to claim 1 or 2, wherein adjusting at least one of the actual correction torque of the propulsion system or the actual articulation angle of the articulation system of the actively articulated tunnel boring machine comprises:

adjusting a first target correction torque of the propulsion system to obtain a third target correction torque and adjusting a first target articulation angle of the articulation system to obtain a third target articulation angle, in a case where there is a deviation between the actual position of the actively articulated tunnel boring machine and the planned tunneling trajectory; and

adjusting the actual correction torque to match the actual correction torque with the third target correction torque, and adjusting the actual articulation angle to match the actual articulation angle with the third target articulation angle;

optionally, adjusting the first target correction torque of the propulsion system to obtain the third target correction torque and adjusting the first target articulation angle of the articulation system to obtain the third target articulation angle comprises:

calculating, based on the actual position of the actively articulated tunnel boring machine, a planned attitude corresponding to the actual position on the planned tunneling trajectory; and

adjusting the first target correction torque to obtain the third target correction torque, and adjusting the first target articulation angle to obtain the third target articulation angle, based on the attitude deviation between the actual attitude of the actively articulated tunnel boring machine and the planned attitude;

optionally, the propulsion control method further comprising:

obtaining sample correction torques, sample articulation angles, and sample attitude deviations; and

training a machine learning model, using the sample correction torques, the sample articulation angles, and the sample attitude deviations as training data, with sample correction torque adjustment amounts and sample articulation angle adjustment amounts as label values, to obtain a trained adjustment model, wherein adjusting the first target correction torque to obtain the third target correction torque, and adjusting the first target articulation angle to obtain the third target articulation angle, based on the attitude deviation between the actual attitude of the actively articulated tunnel boring machine and the planned attitude comprises:

obtaining a second correction torque adjustment amount and a second articulation angle adjustment amount by inputting the first target correction torque, the first target articulation angle, and the attitude deviation into the adjustment model; and

adjusting the first target correction torque using the second correction torque adjustment amount to obtain the third target correction torque, and adjusting the first target articulation angle using the second articulation angle adjustment amount to obtain the third target articulation angle.

6. The propulsion control method according to any one of claims 1 to 5, wherein calculating the planned tunneling trajectory comprises:

obtaining a first trajectory deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the actively articulated tunnel boring machine, as well as a second trajectory deviation, a second deviation speed, and a second deviation acceleration corresponding to an end position of the actively articulated tunnel boring machine, wherein the second trajectory deviation is determined based on the segment uplift amount and a curvature of the designed axis;

constructing a trajectory deviation polynomial between the planned tunneling trajectory and the designed axis based on a driving position and the initial position of the actively articulated tunnel boring machine;

solving, based on the first trajectory deviation, the first deviation speed, the first deviation acceleration, the second trajectory deviation, the second deviation speed, and the second deviation acceleration, the trajectory deviation polynomial to obtain values of unknown constants of the trajectory deviation polynomial;

obtaining a trajectory deviation corresponding to the actual position using the trajectory deviation polynomial; and

obtaining the planned tunneling trajectory based on the trajectory deviation.

7. The propulsion control method according to claim 2, wherein:

calculating a planned tunneling trajectory comprises:

obtaining a first trajectory deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the actively articulated tunnel boring machine, as well as a second trajectory deviation, a second deviation speed, and a second deviation acceleration corresponding to an end position of the actively articulated tunnel boring machine, wherein the second trajectory deviation is determined based on the segment uplift amount and a curvature of the designed axis;

constructing a trajectory deviation polynomial between the planned tunneling trajectory and the designed axis based on a driving position and the initial position of the actively articulated tunnel boring machine;

solving, based on the first trajectory deviation, the first deviation speed, the first deviation acceleration, the second trajectory deviation, the second deviation speed, and the second deviation acceleration, the trajectory deviation polynomial to obtain values of unknown constants of the trajectory deviation polynomial;

obtaining a trajectory deviation corresponding to the actual position using the trajectory deviation polynomial; and

obtaining the planned tunneling trajectory based on the trajectory deviation;

adjusting the planned tunneling trajectory comprises:

using a trajectory deviation corresponding to the current position as the second trajectory deviation during the calculation of the planned tunneling trajectory.

8. The propulsion control method according to claim 3 or 5, further comprising:

obtaining a current working mode of the actively articulated tunnel boring machine, which comprises an advance mode or a continuous mining mode, wherein adjusting the actual correction torque comprises:

adjusting the actual correction torque by adjusting a propulsion cylinder state of the propulsion system according to the current working mode.

9. The propulsion control method according to any one of claims 1 to 8, further comprising at least one of:

calculating an actual propulsion speed of the actively articulated tunnel boring machine, and controlling the actual propulsion speed to match a target propulsion speed; or

calculating an actual total thrust of the actively articulated tunnel boring machine, and controlling the actual total thrust to match the target total thrust.

10. A controller of an actively articulated tunnel boring machine, comprising:

a data obtaining module configured to obtain an actual position of the actively articulated tunnel boring machine, a designed axis, and a segment uplift amount;

a data processing module configured to calculate a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount; and

a control module configured to adjust at least one of an actual correction torque of a propulsion system or an actual articulation angle of an articulation system of the actively articulated tunnel boring machine to match the actual position of the actively articulated tunnel boring machine with the planned tunneling trajectory.

11. The controller according to claim 10, wherein:

the data obtaining module is further configured to obtain a clearance between a shield tail of the actively articulated tunnel boring machine and a segment in a predetermined direction; and

the data processing module is further configured to adjust the planned tunneling trajectory in a case where the clearance in the predetermined direction is less than a clearance threshold and the actively articulated tunnel boring machine is excavating in the predetermined direction.

12. A controller of an actively articulated tunnel boring machine, comprising:

a memory; and

a processor coupled to the memory, the processor configured to, based on instructions stored in the memory, carry out the propulsion control method according to any one of claims 1 to 9.

13. A control system for an actively articulated tunnel boring machine, comprising:

the controller according to any one of claims 10 to 12;

a guidance measurement module configured to measure the position and attitude of the actively articulated tunnel boring machine;

a propulsion system configured to actuate movement of at least some propulsion cylinders of the actively articulated tunnel boring machine; and

an articulation system configured to control movement of articulation cylinders.

14. The control system according to claim 13, further comprising at least one of:

a shield tail clearance measurement module configured to measure a clearance between a shield tail of the actively articulated tunnel boring machine and a segment;

sensors configured to measure a first pressure value and a first stroke value of some or all of the cylinders among the at least some propulsion cylinders; and measure a second pressure value and a second stroke value of some or all of articulation cylinders; or

an interaction module configured to display information and receive user input information.

15. A computer-readable storage medium stored thereon computer program instructions that, when executed by a processor, implement the propulsion control method according to any one of claims 1 to 9.