PROPULSION CONTROL METHOD, CONTROLLER AND CONTROL SYSTEM FOR TUNNEL BORING MACHINE, AND STORAGE MEDIUM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present disclosure is based on and claims priority of Chinese application for invention No. 202410054016.4, 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, a control system for a tunnel boring machine, and a storage medium.

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. 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 a tunnel boring machine, including: obtaining an actual position of the 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 controlling the tunnel boring machine to match the actual position of the tunnel boring machine with the planned tunneling trajectory.

[0005] In some embodiments, obtaining a clearance between a shield tail of the 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 tunnel boring machine is excavating in the predetermined direction.

[0006] In some embodiments, controlling the tunnel boring machine includes: adjusting a first target correction torque to obtain a second target correction torque in a case where there is a deviation between the actual position of the tunnel boring machine and the planned tunneling trajectory; and adjusting an actual correction torque to match the actual correction torque with the second target correction torque.

[0007] In some embodiments, adjusting the first target correction torque to obtain the second target correction torque includes: calculating, based on the actual position of the 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 tunnel boring machine and the planned attitude, the first target correction torque to obtain the second target correction torque.

[0008] In some embodiments, obtaining a current working mode of the tunnel boring machine, the current working mode including an advance mode or a continuous mining mode, where adjusting the actual correction torque includes: adjust the actual correction torque by adjusting a cylinder state of the tunnel boring machine according to the current working mode.

[0009] 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, where 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 includes: obtaining a 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 correction torque adjustment amount to obtain the second target correction torque.

[0010] In some embodiments, calculating the planned tunneling trajectory includes: obtaining a first trajectory deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the 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 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 tunnel boring machine; solving, based on the first trajectory deviation, the first deviation speed, the first deviation acceleration, the second trajectory deviation, the second

includes an advance mode or a continuous mining mode. The actual correction torque is adjusted by adjusting a cylinder state of the tunnel boring machine according to the current working mode.

[0090] In the continuous mining mode, some cylinders retract during the propulsion process to enable partial segment assembly. During tunneling in the continuous mining mode, i.e., under conditions where some cylinders lack pressure due to segment assembly, the remaining active cylinders of the propulsion system are controlled to adjust and stabilize the actual correction torque until it reaches the target correction torque, thereby ensuring that the actual position during propulsion closely follows the planned trajectory.

[0091] In the above embodiment, by adjusting and stabilizing the actual correction torque to achieve the target correction torque, 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.

[0092] In some embodiments of the present disclosure, based on project construction requirements, an interaction module receives a tunneling efficiency mode selected by the user. This tunneling efficiency mode includes a speed control mode and a thrust control mode.

[0093] In some embodiments, in the speed control mode, an actual propulsion speed is calculated for the tunnel boring machine; the actual propulsion speed is controlled to match the target propulsion speed, for example, keeping the actual propulsion speed within an allowable range of the target propulsion speed.

[0094] For example, the actual propulsion speed of the tunnel boring machine can be determined based on the stroke value of the cylinder. For example, the stroke value of the cylinder at time t1 is S1, the stroke value of the cylinder at time t2 is S2, and the speed $V=(S2-S1)/(t2-t1)$. This target propulsion speed is input by the user via an interaction module.

[0095] In some embodiments, in the speed control mode, the controller adjusts and stabilizes the actual propulsion speed of the propulsion system to reach the target propulsion speed when some cylinder thrusts are absent due to segment assembly.

[0096] In the above embodiment, by controlling the propulsion speed of the tunnel boring machine, construction quality and efficiency can be enhanced. Additionally, through the automatic control of the propulsion system, operator tasks during the tunneling process are reduced, thereby elevating the automation level of shield tunneling construction and minimizing the impact of human factors.

[0097] In some embodiments, an actual total thrust of the tunnel boring machine is calculated in a thrust control mode; and the actual total thrust is controlled to match a target total thrust, for example, remaining the actual total thrust within a target total thrust range. The target total thrust is input by the user via the interaction module. The actual total thrust of the tunnel boring machine is the sum of the pressures of all propulsion cylinders.

[0098] In some embodiments, in the thrust control mode, the controller controls the propulsion system to adjust and stabilize the actual total thrust to reach the target total thrust when cylinder thrust is partially absent during segment assembly.

[0099] In the above embodiment, by controlling the total thrust of the tunnel boring machine, construction quality and efficiency can be improved. Additionally, through the automatic control of the propulsion system, operator tasks during the tunneling process are reduced, which improves the automation level of shield construction and minimizes the impact of human factors.

[00100] In the embodiments of this disclosure, the tunnel boring machine can achieve propulsion along a planned axis at preset efficiency by adjusting the axial thrust cylinders of the propulsion system when operating in normal advance mode or continuous mining mode.

[00101] Figure 5 is a schematic structure diagram of a controller for a tunnel boring machine according to some embodiments of the present disclosure. The controller includes a data obtaining module 510, a data processing module 520, and a control module 530.

[00102] The data obtaining module 510 is configured to obtain an actual position of the tunnel boring machine, a designed axis, and a segment uplift amount.

[00103] In some embodiments, the data obtaining module 510 is further configured to obtain a clearance between a shield tail of the 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 a segment, a clearance between the left side of the shield tail and a segment, a clearance between the upper side of the shield tail and a segment, and a clearance between the lower side of the shield tail and a segment.

[00104] In some embodiments, the data obtaining module 510 is further configured to obtain a current working mode of the tunnel boring machine, the current working mode including an advance mode or a continuous mining mode.

[00105] The data processing module 520 is configured to calculate a planned tunneling trajectory based on the actual position, the designed axis, and the segment uplift amount.

[00106] 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.

[00107] In some embodiments, the data processing module 520 obtains a first trajectory deviation, a first deviation speed, and a first deviation acceleration corresponding to an initial position of the 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 tunnel boring machine, where the second trajectory deviation is determined based on the segment uplift amount and the 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 tunnel boring machine; solves, 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; obtains a trajectory deviation corresponding to the actual position using the trajectory deviation polynomial; obtains the planned tunneling trajectory based on the trajectory deviation.

[00108] In some embodiments, the data processing module 520 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 tunnel boring machine is excavating in the predetermined direction. For example, a trajectory deviation corresponding to a 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 segment and enhance operational safety.

[00109] A control module 530 is configured to control the tunnel boring machine to match the actual position of the tunnel boring machine with the planned tunneling trajectory.

What is claimed is:

1. A propulsion control method for a tunnel boring machine, comprising:

obtaining an actual position of the 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

controlling the tunnel boring machine to match the actual position of the 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 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 tunnel boring machine is excavating in the predetermined direction.

3. The propulsion control method according to claim 1 or 2, wherein controlling the tunnel boring machine comprises:

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

adjusting an actual correction torque to match the actual correction torque with the second target correction torque.

4. The propulsion control method according to claim 3, wherein adjusting the first target correction torque to obtain the second target correction torque comprises:

calculating, based on the actual position of the 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 tunnel boring machine and the planned attitude, the first target correction torque to obtain the second target correction torque.

5. The propulsion control method according to claim 3 or 4, further comprising:

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

adjust the actual correction torque by adjusting a cylinder state of the tunnel boring machine according to the current working mode.

6. The propulsion control method according to claim 4, further 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 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 correction torque adjustment amount to obtain the second target correction torque.

7. The propulsion control method according to claim 1 or 6, 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 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 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 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.

8. The propulsion control method according to claim 2, 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 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 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 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.

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 tunnel boring machine, and controlling the actual propulsion speed to match a target propulsion speed; or

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

10. A controller of a tunnel boring machine, comprising:

a data obtaining module configured to obtain an actual position of the 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 control the tunnel boring machine to match the actual position of the 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 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 tunnel boring machine is excavating in the predetermined direction.

12. A controller for a 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 a tunnel boring machine, comprising:

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

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

a propulsion system configured to actuate the movement of at least some cylinders of the tunnel boring machine.

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 tunnel boring machine and a segment;

sensors configured to measure a pressure value and a stroke value of some or all of the cylinders among the at least some 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.