

# **PROPULSION CONTROL METHOD, CONTROLLER AND CONTROL SYSTEM FOR 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, and 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 a construction 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

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.

[0011] 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 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.

[0012] In some embodiments, calculating an actual propulsion speed of the tunnel boring machine; and controlling the actual propulsion speed to match a target propulsion speed.

[0013] In some embodiments, calculating an actual total thrust of the tunnel boring machine; and controlling the actual total thrust to match the target total thrust.

[0014] According to another aspect of the present disclosure, there is further provided a controller for a tunnel boring machine, including: 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.

[0015] In some embodiments, 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.

[0016] According to another aspect of the present disclosure, there is further provided a controller for a 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.

[0017] According to another aspect of the present disclosure, there is also provided a control system for a tunnel boring machine, including: the controller described above; 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.

[0018] In some embodiments, the control system further includes: a shield tail clearance measurement module configured to measure a clearance between a shield tail of the tunnel boring machine and a segment.

[0019] In some embodiments, the control system further includes: sensors configured to measure a pressure value and a stroke value of some or all of the cylinders among the at least some cylinders.

5 [0020] In some embodiments, the control system further includes: an interaction module configured to display information and receive user input information.

[0021] According to another aspect of the present disclosure, there is further provided a computer-readable storage medium having stored thereon computer program instructions that, when executed by a processor, implement the aforementioned propulsion control method.

10 [0022] According to another aspect of the present disclosure, there is further provided a computer program, including: instructions that, when executed by a processor, cause the processor to perform the aforementioned propulsion control method.

[0023] Other features and advantages of the present invention will become apparent from the following detailed description of exemplary embodiments of the present disclosure with reference to the accompanying  
15 drawings.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

[0024] The accompanying drawings, which are incorporated in and constitute a portion of this specification, illustrate embodiments of the present disclosure and, together with the description, serve to explain the principles  
20 of the present disclosure.

[0025] The present disclosure will be more clearly understood from the following detailed description with reference to the accompanying drawings, in which:

[0026] Figure 1 is a flowchart of a propulsion control method for a tunnel boring machine according to some embodiments of the present disclosure;

25 [0027] Figure 2 is a horizontal schematic diagram of a tunneling trajectory according to some embodiments of the present disclosure;

[0028] Figure 3 is a flowchart of a propulsion control method for a tunnel boring machine according to other embodiments of the present disclosure;

[0029] Figure 4 is a flowchart of a propulsion control method for a tunnel boring machine according to still  
30 other embodiments of the present disclosure;

[0030] Figure 5 is a schematic structure diagram of a controller for a tunnel boring machine according to some embodiments of the present disclosure;

[0031] Figure 6 is a schematic structure diagram of a controller for a tunnel boring machine according to other embodiments of the present disclosure;

35 [0032] Figure 7 is a schematic structure diagram of a controller for a tunnel boring machine according to still other embodiments of the present disclosure;

[0033] Figure 8 is a schematic structure diagram of a control system for a tunnel boring machine according to some embodiments of the present disclosure; and

[0034] Figure 9 is a schematic structure diagram of a control system for a tunnel boring machine according  
40 to other embodiments of the present disclosure.

[0035] It should be understood that the dimensions of the various parts shown in the drawings are not necessarily drawn to the actual scale. In addition, the same or similar reference signs are used to denote the same or similar components.

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## DETAILED DESCRIPTION OF THE EMBODIMENTS

[0036] Various exemplary embodiments of the present disclosure will now be described in detail with reference to the accompanying drawings. Notice that, unless otherwise specified, the relative arrangement, numerical expressions and values of the components and steps set forth in these examples do not limit the scope of the invention.

10 [0037] At the same time, it should be understood that, for ease of description, the dimensions of the various parts shown in the drawings are not drawn to actual proportions.

[0038] The following description of at least one exemplary embodiment is in fact merely illustrative and is in no way intended as a limitation to the invention, its application or use.

[0039] Techniques, methods, and apparatus known to those of ordinary skill in the relevant art may not be  
15 discussed in detail, but where appropriate, these techniques, methods, and apparatuses should be considered as part of the specification.

[0040] Of all the examples shown and discussed herein, any specific value should be construed as merely illustrative and not as a limitation. Thus, other examples of exemplary embodiments may have different values.

[0041] Notice that, similar reference numerals and letters are denoted by the like in the accompanying  
20 drawings, and therefore, once an item is defined in a drawing, there is no need for further discussion in the accompanying drawings.

[0042] In recent years, with the advancement of technology, relevant research on the propulsion control of tunnel boring machines has gradually emerged. For instance, in continuous mining mode, the tunneling trajectory can be maintained within an allowable range of the designed axis by stabilizing and adjusting the resultant force  
25 point of the propulsion system. However, the tunneling conditions of a tunnel boring machine may vary significantly with geological conditions. Maintaining excavation along a designed axis poses safety risks in a case where navigating tunnel turns or encountering segment uplift. Moreover, in a case where the total propulsion thrust varies, the control scheme for the resultant force point exhibits instability in steering effects. This disclosure provides a propulsion control method, a controller, a control system, and a storage medium for a  
30 tunnel boring machine, which are capable of reducing safety risks associated with maintaining excavation along the designed axis in a case where navigating tunnel turns or encountering segment uplift.

[0043] For a clear understanding of the object of the present disclosure, its technical solution and advantages, the present disclosure will be further described in detail below in conjunction with the accompanying drawings and embodiments.

35 [0044] Figure 1 is a flowchart of a propulsion control method for a tunnel boring machine according to some embodiments of the present disclosure.

[0045] In step 110, an actual position of the tunnel boring machine, a designed axis, and a segment uplift amount are obtained.

[0046] In some embodiments, the actual position and the attitude of the tunnel boring machine are determined  
40 by a guidance measurement module, or the actual position of the tunnel boring machine is derived from stroke

values of some or all of the cylinders of a propulsion system, as measured by sensors. The segment uplift amount is determined by comparing an upward or downward displacement of a segment after the segment has moved a certain distance away from the shield tail. The uplift amount may be input by a user via an interaction module or directly transmitted to a controller after being detected by sensors. The designed axis is a preset trajectory.

5 [0047] In step 120, a planned tunneling trajectory is calculated based on the actual position, the designed axis, and the segment uplift amount.

[0048] In some embodiments, as shown in Figure 2, within tunnel turns, the planned tunneling trajectory is located on an inner side of designed axis bends, thereby controlling and reducing construction risks. The dashed line in Figure 2 represents the planned tunneling trajectory, while the solid line represents the designed axis. The  
10 distance between the planned tunneling trajectory and the designed axis in the horizontal direction is related to the curvature of the designed axis, showing a positive correlation: the greater the curvature, the larger the distance. For example, a curve with a radius of 800m corresponds to a distance of 5mm. A curve with a radius of 500m corresponds to a distance of 10mm, etc.

[0049] In some embodiments, under conditions of segment uplift, the planned tunneling trajectory is  
15 positioned below the designed axis, thereby reducing the deviation between the completed tunnel and the designed axis. For example, given that the segment uplifts by 20mm after traveling a certain distance beyond the shield tail, the planned tunneling trajectory will be calculated to be 20mm below the designed axis.

[0050] In some embodiments, the controller 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  
20 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 the 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  
25 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; and obtains the planned tunneling trajectory based on the trajectory deviation.

[0051] In some embodiments, a first-order partial derivative is taken with respect to the trajectory deviation  
30 polynomial to obtain a speed deviation polynomial, based on the driving position; and a second-order partial derivative is taken with respect to the trajectory deviation polynomial to obtain an acceleration deviation polynomial, based on the driving position, resulting in three polynomials. By substituting the first trajectory deviation, the first deviation speed, and the first deviation acceleration corresponding to the initial position of the tunnel boring machine, as well as the second trajectory deviation, the second deviation speed, and the second  
35 deviation acceleration corresponding to the end position of the tunnel boring machine into the polynomials, the values of unknown constants of the trajectory deviation polynomial are then solved. Subsequently, the actual position is substituted into this trajectory deviation polynomial to obtain a trajectory deviation. This trajectory deviation is then transformed to calculate the planned tunneling trajectory.

[0052] For example, the trajectory deviation polynomial is:

40 [0053] 
$$\mathbf{Yh(s)} = \mathbf{a_0} + \mathbf{a_1(s - s_0)} + \mathbf{a_2(s - s_0)^2} + \mathbf{a_3(s - s_0)^3} + \mathbf{a_4(s - s_0)^4} + \mathbf{a_5(s - s_0)^5}$$

[0054]  $\mathbf{Yv}(s) = \mathbf{a}_6 + \mathbf{a}_7(s - s_0) + \mathbf{a}_8(s - s_0)^2 + \mathbf{a}_9(s - s_0)^3 + \mathbf{a}_{10}(s - s_0)^4 + \mathbf{a}_{11}(s - s_0)^5$

[0055] where,  $s_0$  denotes initial position, for example, expressed as initial mileage;  $s$  denotes driving position expressed as drive mileage, for example,  $s_0 < s < s_1$ , where  $s_1$  denotes end position, for example, expressed as end mileage;  $\mathbf{Yh}(s)$  denotes horizontal deviation between the planned tunneling trajectory and the designed axis;  $\mathbf{Yv}(s)$  denotes vertical deviation between the planned tunneling trajectory and the designed axis, and  $\mathbf{a}_0, \mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3, \mathbf{a}_4, \mathbf{a}_5, \mathbf{a}_6, \mathbf{a}_7, \mathbf{a}_8, \mathbf{a}_9, \mathbf{a}_{10}, \mathbf{a}_{11}$  are unknown constants of the trajectory deviation polynomial.

[0056] The first trajectory deviation, first deviation speed, and first deviation acceleration are known quantities. That is, the horizontal deviation, vertical deviation, horizontal deviation speed, vertical deviation speed, horizontal deviation acceleration, and vertical deviation acceleration of the initial mileage are all known quantities. The end mileage could be, for example, the upcoming 3rd ring to be advanced. Those skilled in the art should understand that this end mileage can be selected according to actual situations. The second trajectory deviation is determined based on the segment uplift amount and the curvature of the designed axis, while the second deviation speed and the second deviation acceleration are set to zero. That is, the horizontal deviation speed, vertical deviation speed, horizontal deviation acceleration, and vertical deviation acceleration corresponding to the end mileage are zero. The value of vertical deviation is equal to the negative of the segment uplift amount, and the value of horizontal deviation is determined according to a curvature corresponding to the designed axis, for example, 5 times the curvature. Those skilled in the art should understand that the horizontal deviation and the multiple factor of curvature can be set according to actual situations.

[0057] Taking the first-order derivative of  $\mathbf{Yh}(s) = \mathbf{a}_0 + \mathbf{a}_1(s - s_0) + \mathbf{a}_2(s - s_0)^2 + \mathbf{a}_3(s - s_0)^3 + \mathbf{a}_4(s - s_0)^4 + \mathbf{a}_5(s - s_0)^5$  yields  $\mathbf{Yh}(s)' = \mathbf{a}_1 + 2\mathbf{a}_2(s - s_0) + 3\mathbf{a}_3(s - s_0)^2 + 4\mathbf{a}_4(s - s_0)^3 + 5\mathbf{a}_5(s - s_0)^4$ . Taking the second-order derivative of  $\mathbf{Yh}(s) = \mathbf{a}_0 + \mathbf{a}_1(s - s_0) + \mathbf{a}_2(s - s_0)^2 + \mathbf{a}_3(s - s_0)^3 + \mathbf{a}_4(s - s_0)^4 + \mathbf{a}_5(s - s_0)^5$  yields  $\mathbf{Yh}(s)'' = 2\mathbf{a}_2 + 6\mathbf{a}_3(s - s_0) + 12\mathbf{a}_4(s - s_0)^2 + 20\mathbf{a}_5(s - s_0)^3$ . Taking the first-order derivative of  $\mathbf{Yv}(s) = \mathbf{a}_6 + \mathbf{a}_7(s - s_0) + \mathbf{a}_8(s - s_0)^2 + \mathbf{a}_9(s - s_0)^3 + \mathbf{a}_{10}(s - s_0)^4 + \mathbf{a}_{11}(s - s_0)^5$  yields  $\mathbf{Yv}(s)' = \mathbf{a}_7 + 2\mathbf{a}_8(s - s_0) + 3\mathbf{a}_9(s - s_0)^2 + 4\mathbf{a}_{10}(s - s_0)^3 + 5\mathbf{a}_{11}(s - s_0)^4$ . Taking the second-order derivative of  $\mathbf{Yv}(s) = \mathbf{a}_6 + \mathbf{a}_7(s - s_0) + \mathbf{a}_8(s - s_0)^2 + \mathbf{a}_9(s - s_0)^3 + \mathbf{a}_{10}(s - s_0)^4 + \mathbf{a}_{11}(s - s_0)^5$  yields  $\mathbf{Yv}(s)'' = 2\mathbf{a}_8 + 6\mathbf{a}_9(s - s_0) + 12\mathbf{a}_{10}(s - s_0)^2 + 20\mathbf{a}_{11}(s - s_0)^3$ .

[0058] By substituting the horizontal deviation, vertical deviation, horizontal deviation speed, vertical deviation speed, horizontal deviation acceleration, and vertical deviation acceleration of the initial mileage, as well as the horizontal deviation, vertical deviation, horizontal deviation speed, vertical deviation speed, horizontal deviation acceleration, and vertical deviation acceleration corresponding to the ending mileage into the above formula,  $\mathbf{a}_0, \mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3, \mathbf{a}_4, \mathbf{a}_5, \mathbf{a}_6, \mathbf{a}_7, \mathbf{a}_8, \mathbf{a}_9, \mathbf{a}_{10}, \mathbf{a}_{11}$  can be derived.

[0059] Substituting the current actual mileage into the equations  $\mathbf{Yh}(s) = \mathbf{a}_0 + \mathbf{a}_1(s - s_0) + \mathbf{a}_2(s - s_0)^2 + \mathbf{a}_3(s - s_0)^3 + \mathbf{a}_4(s - s_0)^4 + \mathbf{a}_5(s - s_0)^5$  and  $\mathbf{Yv}(s) = \mathbf{a}_6 + \mathbf{a}_7(s - s_0) + \mathbf{a}_8(s - s_0)^2 + \mathbf{a}_9(s - s_0)^3 + \mathbf{a}_{10}(s - s_0)^4 + \mathbf{a}_{11}(s - s_0)^5$ , with known variables, horizontal deviation  $\mathbf{Yh}(s)$  and vertical deviation  $\mathbf{Yv}(s)$  between the planned tunneling trajectory and the designed axis corresponding to the current actual mileage can be computed. Here,  $\mathbf{Yh}(s)$  and  $\mathbf{Yv}(s)$  represent the local tunneling trajectory in the Frenet coordinate system. The coordinates in the Cartesian coordinate system, namely the planned tunneling trajectory, can be obtained through coordinate transformation.

[0060] In step 130, the tunnel boring machine is controlled to match the actual position of the tunnel boring machine with the planned tunneling trajectory.

[0061] In some embodiments, in a case where there is a deviation between the actual position of the tunnel boring machine and the planned tunneling trajectory, a first target correction torque is adjusted to obtain a second target correction torque; and an actual correction torque is adjusted to match the actual correction torque with the second target correction torque. The first target correction torque is a target correction torque before adjustment, and the second target correction torque is a target correction torque after adjustment. The actual correction torque is adjusted so that it reaches the adjusted target correction torque, thereby reducing the deviation between a future actual position and the planned tunneling trajectory and ensuring that the actual tunneling trajectory remains aligned with the planned tunneling trajectory.

[0062] In the above embodiments, the planned tunneling trajectory is dynamically determined based on information such as the designed axis, actual position, and segment uplift amount, and then the tunnel boring machine is controlled to match the actual position of the tunnel boring machine with the planned tunneling trajectory, which enables the reduction of deviations between future actual positions and the planned tunneling trajectory, thereby mitigating safety risks associated with the tunnel boring machine maintaining excavation along the designed axis in a case where navigating tunnel turns or encountering segment uplift.

[0063] Figure 3 is a propulsion control method for a tunnel boring machine according to other embodiments of the present disclosure.

[0064] In step 310, the actual position of the tunnel boring machine, the designed axis, and the segment uplift amount, as well as a clearance between the shield tail of the tunnel boring machine and the segment in a predetermined direction are obtained.

[0065] In some embodiments, the clearance between the shield tail and the segment is measured in real time by a shield tail clearance measurement module. 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.

[0066] In step 320, a planned tunneling trajectory is calculated based on the actual position, the designed axis, and the segment uplift amount.

[0067] In step 330, 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, the planned tunneling trajectory is adjusted.

[0068] In some embodiments, the trajectory deviation corresponding to the current position is taken as the second trajectory deviation in calculating the planned tunneling trajectory, and the planned tunneling trajectory is recalculated.

[0069] For example, if the clearance between the right side of the shield tail and a segment is less than a first threshold, and the horizontal deviation at the end mileage is greater than the horizontal deviation at the initial mileage, the horizontal trajectory deviation corresponding to the current actual position is taken as the horizontal deviation value at the end mileage for replanning the tunneling trajectory.

[0070] If the clearance between the left side of the shield tail and a segment is less than a second threshold, and the horizontal deviation at the end mileage is less than the horizontal deviation at the initial mileage, the

horizontal trajectory deviation corresponding to the current actual position is taken as the horizontal deviation value at the end mileage for replanning the tunneling trajectory.

[0071] If the clearance between the upper side of the shield tail and a segment is less than a third threshold, and the vertical deviation at the end mileage is greater than the vertical deviation at the initial mileage, the vertical trajectory deviation corresponding to the current actual position is taken as the vertical deviation at the end mileage for replanning the tunneling trajectory.

[0072] If the clearance between the lower side of the shield tail and a segment is less than a fourth threshold, and the vertical deviation at the end mileage is less than the vertical deviation at the initial mileage, the vertical trajectory deviation corresponding to the current actual position is taken as the vertical deviation at the end mileage for replanning the tunneling trajectory.

[0073] The first, second, third, and fourth thresholds mentioned above can be the same or different, and can be set according to actual situations.

[0074] In step 340, the tunnel boring machine is controlled to match the actual position of the tunnel boring machine with the planned tunneling trajectory.

[0075] In the above embodiments, during the startup or continuous excavation of the tunnel boring machine, the planned tunneling trajectory is dynamically determined based on information such as the designed axis, actual position, and segment uplift amount. Additionally, by monitoring changes in the shield tail clearance, auxiliary adjustments are made to the planned tunneling trajectory. The tunnel boring machine is then controlled to match the actual position of the tunnel boring machine with the planned tunneling trajectory, thereby reducing deviations between future actual positions and the planned tunneling trajectory. On one hand, it mitigates safety risks associated with the tunnel boring machine maintaining excavation along the designed axis in a case where navigating tunnel turns or encountering segment uplift. On the other hand, by taking into account the impact of attitude adjustments on the segment, it is possible to prevent segment damage and enhance operational safety.

[0076] Figure 4 is a flowchart of a propulsion control method for a tunnel boring machine according to other embodiments of the present disclosure.

[0077] In step 410, a planned attitude corresponding to the actual position on a planned tunneling trajectory is calculated, based on the actual position of the tunnel boring machine.

[0078] In step 420, the first target correction torque is adjusted to obtain a second target correction torque, based on an attitude deviation between an actual attitude of the tunnel boring machine and the planned attitude.

[0079] In some embodiments, the first target correction torque and the attitude deviation are input into a correction torque adjustment model to obtain a correction torque adjustment amount; and the first target correction torque is adjusted using the correction torque adjustment amount to obtain a second target correction torque. The first target correction torque is a preset value, or equals a correction torque initially applied to the propulsion system. The correction torque adjustment model in this embodiment is a machine learning model.

[0080] In some embodiments, sample correction torques and sample attitude deviations are obtained; and the machine learning model is trained, 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.

[0081] For example, the correction torque of the tunnel boring machine is adjusted to change its attitude. Correction torque and attitude information of the tunnel boring machine are collected and used as training data,

with correction torque adjustment amounts as label values of the training data, output values of the machine learning model are compared with the label values, it is determined whether the comparison result meets the requirements of a loss function for constructing the correction torque adjustment model. By means of repeated iterations, parameters of the machine learning model are optimized and adjusted, ensuring that the comparison result ultimately satisfies the loss function requirements for building the correction torque adjustment model. This correction torque adjustment model is then saved.

[0082] By inputting the error between the actual horizontal attitude and the planned horizontal attitude, as well as the error between the actual vertical attitude and the planned vertical attitude, into the trained correction torque adjustment model, a correction torque adjustment amount can be obtained. This correction torque adjustment amount is added to the first target correction torque to yield the second target correction torque.

[0083] In some embodiments, the target correction torque includes a target horizontal correction torque and a target vertical correction torque.

[0084] Correction torque is a physical quantity that describes the rotational effect generated by multiple cylinders of a propulsion system around the horizontal and vertical axes of the tunnel boring machine. In related technologies, a resultant force point refers to a combined action point of multiple cylinders of a propulsion system.

[0085] In step 430, an actual correction torque is adjusted to match the actual correction torque with the second target correction torque.

[0086] In some embodiments, an adjustment is made to the cylinder state of the tunnel boring machine to adjust the actual correction torque, to match the actual correction torque with the second target correction torque.

[0087] In some embodiments, the propulsion system enables the cylinders to operate along an axial direction. This propulsion system is arranged on a side of the tunnel boring machine, abuts against and supports the segment, and provides propulsion power for the tunnel boring machine. A correction torque of the cylinders can be determined based on the pressure value of the cylinders.

[0088] In some embodiments, the propulsion system of the tunnel boring machine includes multiple cylinder zones spaced apart in a circumferential direction, with at least one cylinder point located within each cylinder zone. The controller obtains a target total thrust, a target horizontal correction torque, and a target vertical correction torque in the current working mode; constructs a first thrust distribution group to make the first thrust distribution group generates a unit thrust, the first thrust distribution group including first thrust values corresponding to the multiple cylinder zones; constructs a second thrust distribution group to make the second thrust distribution group generates a unit horizontal correction torque, the second thrust distribution group including second thrust values corresponding to the multiple cylinder zones; and construct a third thrust distribution group to make the third thrust distribution group generates a unit vertical correction torque, the third thrust distribution group including third thrust values corresponding to the multiple cylinder zones, the first thrust distribution group, the second thrust distribution group, and the third thrust distribution group being linearly independent; a propulsion force is obtained for each cylinder zone, based on the first thrust distribution group, the second thrust distribution group, the third thrust distribution group, as well as a target thrust, a target horizontal correction torque, and a target vertical correction torque, to control the states of the cylinders in the multiple cylinder zones accordingly.

[0089] In some embodiments, the current working mode of the tunnel boring machine is obtained, which

includes a construction 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  $t_1$  is  $S_1$ , the stroke value of the cylinder at time  $t_2$  is  $S_2$ , and the speed  $V=(S_2-S_1)/(t_2-t_1)$ . 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 construction 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 a construction 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.

[00110] In some embodiments, in a case where there is a deviation between the actual position of the tunnel boring machine and the planned tunneling trajectory, the control module 530 adjusts a first target correction torque to obtain a second target correction torque; and adjusts an actual correction torque to match the actual correction torque with the second target correction torque.

5 [00111] In some embodiments, a planned attitude corresponding to the actual position on the planned tunneling trajectory is calculated, based on the actual position of the tunnel boring machine; and the first target correction torque is adjusted to obtain the second target correction torque, based on an attitude deviation between an actual attitude of the tunnel boring machine and the planned attitude.

[00112] In some embodiments, as shown in FIG. 6, the controller further includes a model training module 610  
10 configured to obtain sample correction torques and sample attitude deviations; and train 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. The control  
15 module 530 inputs the first target correction torque and the attitude deviation into a correction torque adjustment model to obtain a correction torque adjustment amount; and adjusts the first target correction torque using the correction torque adjustment amount to obtain the second target correction torque.

[00113] In some embodiments, the control module 530 is further configured to adjust the actual correction torque by adjusting a cylinder state of the tunnel boring machine according to the current working mode.

20 [00114] In the above embodiments, the planned tunneling trajectory is dynamically determined based on information such as the designed axis, actual position, and segment uplift amount, and then the tunnel boring machine is controlled to match the actual position of the tunnel boring machine with the planned tunneling trajectory, which enables the reduction of deviations between future actual positions and the planned tunneling trajectory, thereby mitigating safety risks associated with the tunnel boring machine maintaining excavation  
25 along the designed axis in a case where navigating tunnel turns or encountering segment uplift.

[00115] In some embodiments of the present disclosure, the data processing module 520 is further configured to calculate the actual propulsion speed of the tunnel boring machine, and the control module 530 is further configured to control the actual propulsion speed to match the target propulsion speed.

[00116] The data processing module 520 is further configured to calculate an actual total thrust of the tunnel  
30 boring machine, and the control module 530 is further configured to control the actual total thrust to match a target total thrust.

[00117] By controlling the propulsion speed and total thrust of the tunnel boring machine, construction quality and efficiency can be improved.

[00118] FIG. 7 is a schematic structural diagram of a controller for a tunnel boring machine according to other  
35 embodiments of the present disclosure. The controller includes a memory 710 and a processor 720, where the memory 710 may be a magnetic disk, flash memory or any other non-volatile storage medium. The memory 710 is used to store instructions of a corresponding embodiment described above. The processor 720 is coupled to the memory 710 and may be implemented as one or more integrated circuits, such as a microprocessor or microcontroller. The processor 720 is used to execute the instructions stored in the memory.

40 [00119] In some embodiments, the processor 720 is coupled to the memory 710 via a bus 730. The controller

may be further connected to an external storage device 750 through a storage interface 740 to access external data, and may be further connected to a network or another computer system (not shown) through a network interface 760, the details of which will not be described herein.

[00120] In this embodiment, by storing data instructions in the memory and processing the aforementioned instructions through the processor, it is possible to reduce the safety risks associated with maintaining excavation along the designed axis in a case where navigating tunnel turns or encountering segment uplift, and address the issue of unstable correction effects in resultant force point control schemes when the total propulsion thrust changes. Additionally, through the automatic control of the propulsion system, operator tasks during the tunneling process are reduced, thereby improving the automation level of shield tunneling construction, minimizing the impact of human factors, and improving construction quality and efficiency.

[00121] Figure 8 is a schematic structure diagram of a control system for a tunnel boring machine according to some embodiments of the present disclosure. The control system includes a controller 810, a guidance measurement module 820 and a propulsion system 830, where the controller 810 has been described in detail in the above embodiments and will not be repeated here. The guidance measurement module 820 and the propulsion system 830 are electrically connected to the controller 810.

[00122] The guidance measurement module 820 is configured to measure the position and attitude of the tunnel boring machine, and the propulsion system 830 is configured to actuate the movement of at least some cylinders of the tunnel boring machine. The propulsion system 830 has its propulsion cylinders working along an axial direction, the propulsion cylinders being arranged on a side of the tunnel boring machine, and abutting against and supporting on the segment to provide propulsion power for the tunnel boring machine. For example, when the tunnel boring machine is in continuous mining mode, the propulsion system 830 drives the movement of a portion of the cylinders.

[00123] In some embodiments, as shown in Figure 9, the control system further includes a shield tail clearance measurement module 910 configured to measure a clearance between a shield tail of the tunnel boring machine and the segment. The tail clearance measurement module 910 is electrically connected to the controller 810. The tail clearance measurement module is, for example, a laser detector.

[00124] In some embodiments, the control system further includes sensors 920 configured to measure a pressure value and a stroke value of some or all of the cylinders among the at least some cylinders. The sensors, may include pressure sensors. Since not all cylinders are equipped with pressure sensors, it is possible to monitor only the pressure and stroke values of some cylinders. For example, the cylinders are grouped for controlling, such as Group A, Group B, Group C, and Group D. Each group contains one or more cylinders, and only one pressure sensor is configured on a specific cylinder in each group. In this case, the pressure sensor monitors the pressure of only one cylinder in each group. The sensors further include, for example, displacement sensors.

[00125] In some embodiments, the control system further includes an interaction module 930 configured to display information and receive user input information. For example, the interaction module displays the tunneling trajectory, and receives user-input values such as segment uplift, target propulsion speed, and target total thrust. The interaction module is, for example, a user terminal such as a host computer.

[00126] In other embodiments, there is provided a computer-readable storage medium stored thereon computer program instructions that, when executed by a processor, implement the steps of the method of the above embodiment. One skilled in the art should understand that, the embodiments of the present disclosure may be

provided as a method, an apparatus, or a computer program product. Therefore, embodiments of the present disclosure can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. Moreover, the present disclosure may take the form of a computer program product embodied on one or more computer-usable non-transitory storage media (including but not limited to disk storage, CD-ROM, optical storage device, etc.) having computer-usable program code embodied therein.

[00127] According to some embodiments of the present disclosure, there is further provided a computer program, including: instructions that, when executed by a processor, cause the processor to preform the propulsion control method described above.

[00128] The present disclosure is described with reference to flowcharts and/or block diagrams of methods, apparatuses (systems) and computer program products according to embodiments of the present disclosure. It should be understood that each process and/or block in the flowcharts and/or block diagrams, and combinations of the processes and/or blocks in the flowcharts and/or block diagrams may be implemented by computer program instructions. The computer program instructions may be provided to a processor of a general purpose computer, a special purpose computer, an embedded processor, or other programmable data processing apparatus to generate a machine such that the instructions executed by a processor of a computer or other programmable data processing apparatus to generate means implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00129] The computer program instructions may also be stored in a computer readable storage device capable of directing a computer or other programmable data processing apparatus to operate in a specific manner such that the instructions stored in the computer readable storage device produce an article of manufacture including instruction means implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00130] These computer program instructions can also be loaded onto a computer or other programmable device to perform a series of operation steps on the computer or other programmable device to generate a computer-implemented process such that the instructions executed on the computer or other programmable device provide steps implementing the functions specified in one or more flows of the flowcharts and/or one or more blocks of the block diagrams.

[00131] Heretofore, the present disclosure has been described in detail. In order to avoid obscuring the concepts of the present disclosure, some details known in the art are not described. Based on the above description, those skilled in the art can understand how to implement the technical solutions disclosed herein.

[00132] The method and apparatus of the present disclosure may be implemented in many ways. For example, the method and apparatus of the present disclosure may be implemented by software, hardware, firmware, or any combination of software, hardware, and firmware. The above sequence of steps of the method is merely for the purpose of illustration, and the steps of the method of the present disclosure are not limited to the above-described specific order unless otherwise specified. In addition, in some embodiments, the present disclosure may also be implemented as programs recorded in a recording medium, which include machine-readable instructions for implementing the method according to the present disclosure. Thus, the present disclosure also covers a recording medium storing programs for executing the method according to the present disclosure.

[00133] Although some specific embodiments of the present disclosure have been described in detail by way

of example, those skilled in the art should understand that the above examples are only for the purpose of illustration and are not intended to limit the scope of the present disclosure. It should be understood by those skilled in the art that the above embodiments may be modified without departing from the scope and spirit of the present disclosure. The scope of the disclosure is defined by the following claims.

**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 a

construction 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:

calculating an actual propulsion speed of the tunnel boring machine; and

controlling the actual propulsion speed to match a target propulsion speed.

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

calculating an actual total thrust of the tunnel boring machine; and

controlling the actual total thrust to match the target total thrust.

11. 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.

12. The controller according to claim 11, 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.

13. 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 10.

14. A control system for a tunnel boring machine, comprising:

the controller according to any one of claims 11 to 13;

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.

15. The control system according to claim 14, further comprising:

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

16. The control system according to claim 14 or 15, further comprising:

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

17. The control system according to any one of claims 14 to 16, further comprising:

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

18. 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 10.

19. A computer program, comprising:

instructions that, when executed by a processor, cause the processor to perform the propulsion control method according to any one of claims 1 to 10.