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# Design and modeling of a walking mechanism for the self-adapting pipeline robot

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**Abstract.** Self-adapting pipeline robot is widely used in many industrial fields and the walking mechanism is its critical part. According to the actual dimensional demand of a certain pipeline and the requirement of self-adapting pipeline robot, a walking mechanism is designed based on the double-cross structure and modelled through utilizing 3D modeling software. The walking mechanism can adjust its size to adapt to pipeline with different diameters. The workbench can be kept in the center of the pipeline by optimization of size of the double-cross structure. There are two driving wheels in the bottom and one driving wheel in the top to constitute three-point type, which can improve the stability and load capacity of the robot. The H-type driving wheel is adopted to improve stability and reliability of the contact between the wheel and the guide. Through optimizing parameters of the double-cross structure, the designed walking mechanism can meet the requirement of the pipeline with diameters from 480mm to 600mm. Furthermore, constructions of the walking mechanism are modelled by the Solidworks modeling software, which can verify the feasibility of the design. Design and modeling of the walking mechanism are propitious to give technical support to maintenance and repair of the pipeline.

## 1. Introduction

Along with development of our country's economy and society, the pipeline has become an important conveying device <sup>[1-3]</sup>. In order to improve life of the pipeline and prevent accident, pipelines must be effectively inspected and maintained <sup>[4, 5]</sup>, and the self-adapting pipeline robot has been developed to meet the maintenance and repair of the pipeline with different diameters <sup>[6, 7]</sup>. For a certain pipeline studied in this research, there are guides and irregularly distributed anti-corrosion blocks in it, which makes its maintenance difficult. Meanwhile, length of the pipeline exceeds 10m, and the diameter of it ranges from 480mm to 600mm, which makes the maintenance harder. Furthermore, the workbench in the maintenance process must be kept in the center of the pipeline, which leads to complex structure of the robot. Therefore, novel robot is needed to meet these strict requirements.

Up to now, many pipeline robots have been developed, such as gas pipeline robot <sup>[8]</sup>, underground pipeline robot <sup>[9]</sup>, inchworm in-pipe robot <sup>[10]</sup>, T-type pipeline robot <sup>[11]</sup>, and so on. However, these robots cannot meet the certain demands in this study. Thus, a walking mechanism is designed based on the double-cross structure and modelled through utilizing 3D modeling software of Solidworks <sup>[12]</sup>. The construction design and structural modeling of the walking mechanism is conducted in this study. Meanwhile, the workbench can take testing equipment, which can improve the maintenance efficiency.



## 2. Construction design

Requirements of the certain pipeline can be summarized into four indexes: 1. range of diameter of the pipeline is 480mm-600mm; 2. the workbench must be kept in the center of the pipeline and it can take some working devices; 3. the wheel can contact steadily with the guide; 4. structure of the robot must be compact and easy to carry. According to these requirements, a double-cross structure is developed in this study, and its kinematic diagram is shown in figure 1. There are two cross structures, as shown of the blue dotted line ABJ-ADI and the red dashed line CEH-CFG, and they are connected at point C, G, and H. The workbench is fixed on slider at point E and that at point F. The structure is symmetric, which indicates the equal relationship shown in Eq. 1. Meanwhile, size of the cross structure ABJ-ADI is twice as much as that of CEH-CFG, which indicates the equal relationship shown in Eq. 2.

$$l_{AB} = l_{AD}, l_{BJ} = l_{DI}, l_{CE} = l_{CF}, l_{EH} = l_{FG} \quad (1)$$

$$l_{AB} = 2l_{BG} = 2l_{CF}, l_{BJ} = 2l_{BC} = 2l_{GF} \quad (2)$$

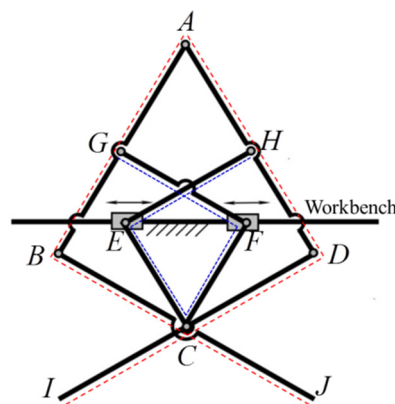


Figure 1. Kinematic diagram of the designed walking mechanism.

Structure composition of the designed walking mechanism is shown in the figure 2. It can be found that there are two lower driving wheels in the bottom side and one upper driving wheel in the top side to constitute a three-point type, which can improve stability and load capacity of the robot. The motors to drive the three wheels are integrated in them, which can improve the compactness and reliability. The two sliders are driven by the driving motor to move on the sliding screw, which leads adjustment of the walking mechanism to adapt the pipeline by the double-cross structure. The workbench is fixed on the slider at point E and that at point F. The H-type driving wheels are adopted to improve stability and reliability of the contact between the wheel and the guide. The force sensors are fixed on the three driving wheels to control the driving motor, which can realize self-adapting of the robot.

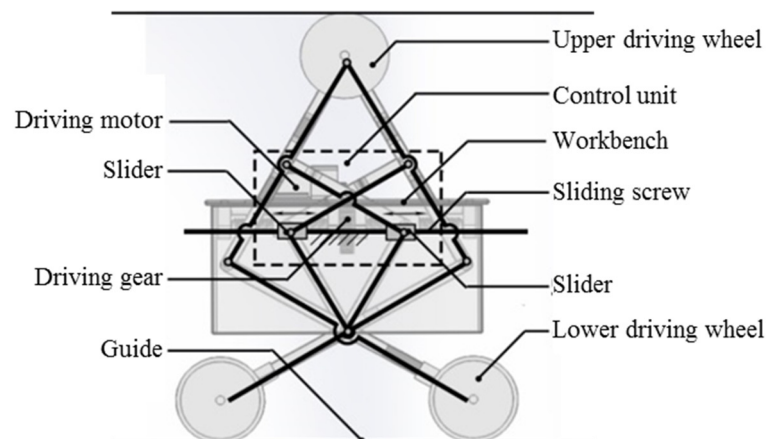


Figure 2. Structure composition of the designed walking mechanism.

Schematic diagram of the designed walking mechanism is shown in figure 3. In order to keep the workbench on the EF platform in the center of the designed walking mechanism, the angle  $\alpha$  between AD and vertical line and the angle  $\beta$  between DI and horizontal line must be optimized. Supposing the perpendicular heights of AB, BJ, BG, and CF are  $h_{AB}$ ,  $h_{BJ}$ ,  $h_{BG}$ , and  $h_{CF}$ , and the total height of the walking mechanism is  $H$ . It can be found that the total height consists of two parts, as shown in Eq. 3. Meanwhile, the perpendicular height of EF can be calculated by Eq. 4.

$$H = h_{AB} + h_{BJ} = l_{AB} \cos \alpha + l_{BJ} \sin \beta \quad (3)$$

$$h_{EF} = h_{IC} + h_{CF} \quad (4)$$

From Eq. 2 it can be found that G and H is the midpoint of rod AB and AD respectively, and C is the midpoint of rod BJ and DI. Meanwhile, the length of CF and BG and the length of CE and DH are equal respectively. Therefore, the Eq. 4 can be derived to Eq. 5 according to these relationships.

$$h_{EF} = h_{IC} + h_{CF} = \frac{1}{2} h_{ID} + h_{BG} = \frac{1}{2} h_{BJ} + \frac{1}{2} h_{AB} = \frac{1}{2} (l_{AB} \cos \alpha + l_{BJ} \sin \beta) = \frac{1}{2} H \quad (5)$$

From Eq. 3 and Eq. 5 it can be found that EF is in the center of the walking mechanism. In other words, the workbench on the EF platform is in the center of the self-adapting pipeline robot, because diameters of the driving wheel in point A, point I, and point J are equal.

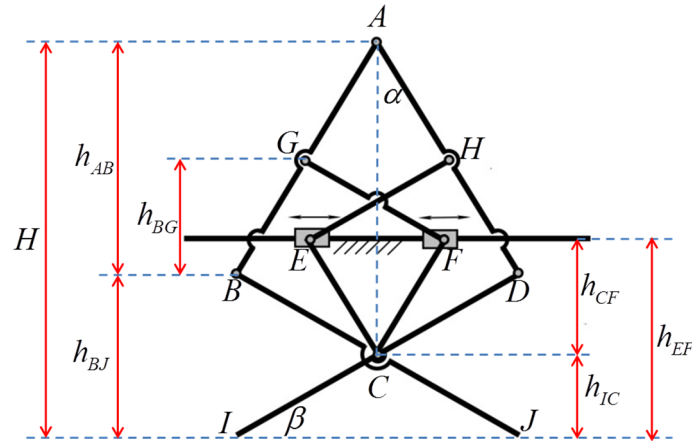


Figure 3. Schematic diagram of the designed walking mechanism.

Diameter of the pipeline ranges from 480mm to 600mm, so its median is 540mm. The radius of the wheel is 45mm determined by the size of the guide. Therefore, total height of the walking mechanism can be calculated by Eq. 6. In order to improve the stability and reliability of the system, perpendicular height of AB and BJ is set to 250mm and 200mm respectively, and angle  $\alpha$  is set to  $25^\circ$ . Dimension parameter of each rod of walking mechanism can be calculated, as shown in Eq. 7. The corresponding lengths of AD (AB), DI (BJ), CF (CE), EH (GF) are 276mm, 307mm, 138mm, and 154mm.

$$H = 540\text{mm} - 45\text{mm} * 2 = 450\text{mm} \quad (6)$$

$$\begin{cases} l_{AD} = l_{AB} = 276\text{mm} \\ l_{DI} = l_{BJ} = 307\text{mm} \\ \beta = 40^\circ \\ l_{CF} = l_{CE} = 138\text{mm} \\ l_{EH} = l_{GF} = 154\text{mm} \end{cases} \quad (7)$$

Further verification is conducted to check whether the walking mechanism can meet requirement of the pipeline with diameter ranges from 480mm to 600mm. From the figure 3 it can be found that the parameters of the walking mechanism have the relationships shown in Eq. 8.

$$\begin{cases} l_{AD} \sin \alpha = l_{CD} \cos \beta \\ l_{AD} \cos \alpha + 2l_{CD} \sin \beta = H \end{cases} \quad (8)$$

When diameter of the pipeline is 480mm, the total height of the walking mechanism  $H_{lower}$  can be calculated by Eq. 9. Meanwhile, when diameter of the pipeline is 600mm, total height of the walking mechanism  $H_{upper}$  can be calculated by Eq. 10.

$$H_{lower} = 480mm - 45mm * 2 = 390mm \quad (9)$$

$$H_{upper} = 600mm - 45mm * 2 = 510mm \quad (10)$$

Therefore, based on the Eq. 1, 2, 3 and 8, the corresponding angle  $\alpha$  between AD and vertical line and angle  $\beta$  between DI and horizontal line can be calculated, as shown in Eq. 11.

$$\alpha_{lower} = 29.2^\circ, \beta_{lower} = 28.9^\circ, \alpha_{upper} = 19.1^\circ, \beta_{upper} = 54.1^\circ \quad (11)$$

### 3. Structural modeling

Construction of the designed walking mechanism is shown in figure 4, which is obtained by the 3D modeling software of Solidworks according to the parameters of the established walking mechanism. From the isometric view of the designed walking mechanism in figure 4(a), it can be found that some dimensional twisted components are used to avoid interference of the system. Adjustment of size of the walking mechanism can be conveniently realized by controlling the driving motor, and the three-point structure can keep the self-adapting pipeline robot move steadily on the guide.

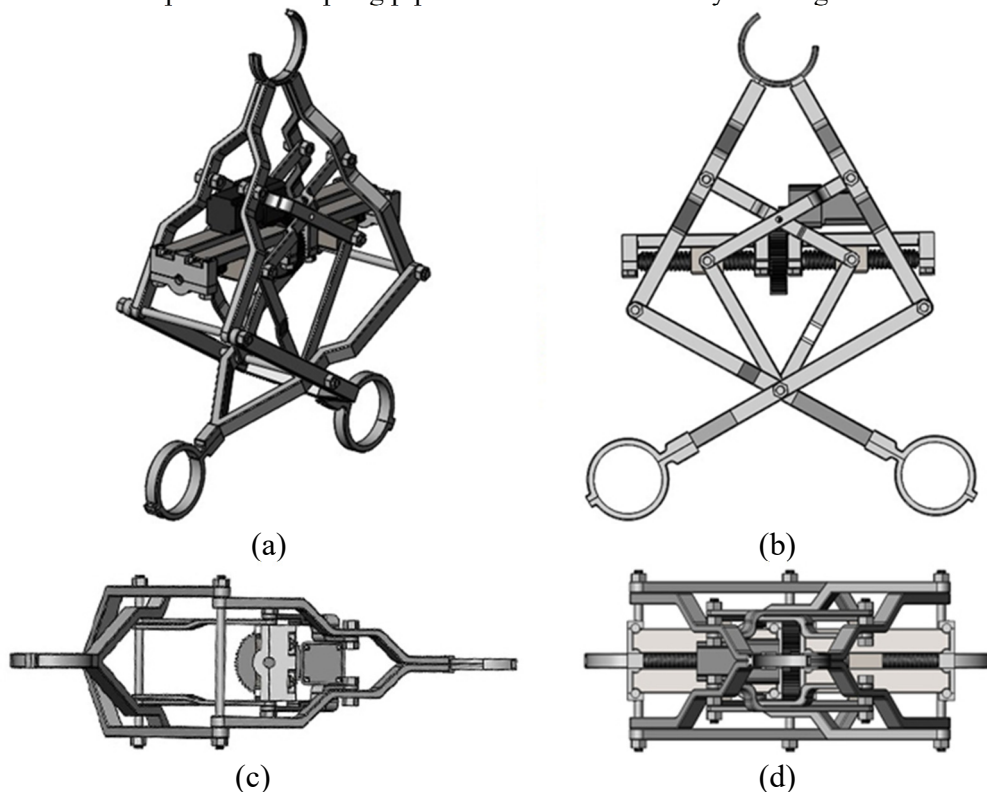


Figure 4. Construction of the designed walking mechanism. (a) isometric view. (b) orthographic view. (c) left view. (d) overhead view.

Three-dimensional model of the self-adapting pipeline robot is shown in figure 5. By making full use of the limited space, the walking mechanism is placed on the adaptive drive system to ensure that it can bear greater force. The various parts of the robot are fastened together in the bolted connections, which can effectively guarantee the strength of the structure. Every supporting rod adopts hollow rectangular steel pipe to ensure that each component has enough strength and avoid accidents such as fracture in the working process. A group of connectors are fixed between the robot body and driving wheel, which not only facilitates installation of the driving wheel, but also increases the convenience of the maintenance of the components.

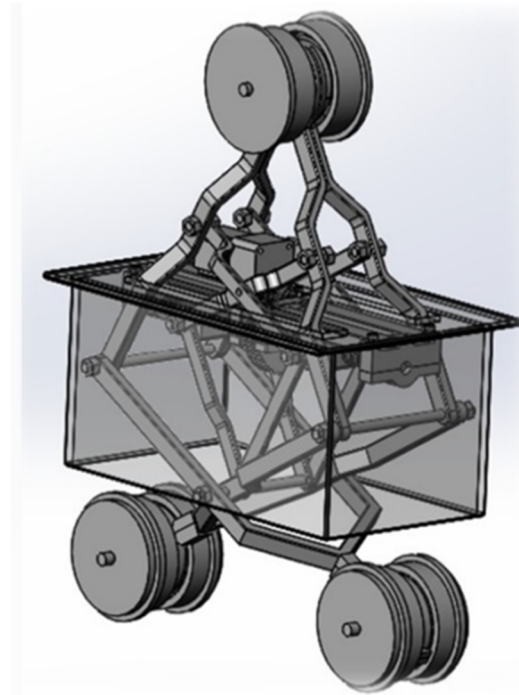


Figure 5. Three-dimensional model of the self-adapting pipeline robot.

#### 4. Conclusions

According to the actual dimensional demand of a certain pipeline and the requirement of self-adapting pipeline robot, a walking mechanism is designed based on the double-cross structure and modelled through utilizing 3D modeling software. Construction design and structural modeling of the walking mechanism is conducted in this study. The following conclusions can be obtained.

(1) The workbench can be kept in center of the pipeline by optimization of size of the double-cross structure. There are two driving wheels in the bottom and one driving wheel in the top to constitute three-point type, which can improve the stability and load capacity of the robot. The H-type driving wheel is adopted to improve stability and reliability of the contact between the wheel and the guide.

(2) Through optimizing parameters of the double-cross structure, the designed walking mechanism can meet requirement of the pipeline with diameters from 480mm to 600mm. The walking mechanism can adjust its size to adapt to pipeline with different diameters.

(3) Constructions of the walking mechanism are modelled by the Solidworks modeling software, which can verify the feasibility of the design. Design and modeling of the walking mechanism are propitious to give technical support to maintenance and repair of the pipeline.



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