A Design of combined pipe cleaning and spraying robot based on new cutting tool material

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Abstract—The combined pipeline cleaning and spraying robot based on new cutting tool material includes four components, namely milling mechanism, walking mechanism, spraying mechanism and external coating supply device. The robot's milling cutter is a special coating cutter. The coating material of the cutter can be used to meet the peeling strength of the pipe surface after spraying. From the view of environmental protection, the robot can reduce the impact of passive process on the environment. According to the actual situation the combination robot can be combined freely, which has a strong practicability.

1. RESEARCH BACKGROUND AND SIGNIFICANCE

As an efficient means of fluid and gas transportation, pipeline transportation is widely used in nuclear industry, petroleum and coal transportation, and people's livelihood. Due to the sealing characteristics and different sizes of pipes, it is very troublesome to detect, repair and maintain the pipeline. At present, the main methods of pipeline cleaning in China are physical method or chemical method. Physical methods include hammering and high pressure water jet cleaning. The labor intensity of the first kind is relatively high, while the second method consumes a lot of clean water, which will discharge a lot of waste water and destroy the local vegetation after cleaning. Chemical cleaning is a technology which uses inorganic acid and ash scale to produce chemical reaction and soluble salt to remove ash scale. The CO₂ gas produced in the chemical reaction can peel off the ash scale, so that part of the ash scale will fall off and be taken out of the pipe by the cleaning solution. However, CO₂ gas will also accumulate at the high point of the ash conveying pipeline or the upper part of the pipeline, forming gas resistance, which will isolate the acid washing liquid from the ash scale on the top of the pipeline, so that the ash scale in the pipeline cannot fully contact with the acid washing liquid to produce chemical reaction. As a result, the ash scale at the bottom of the pipeline has been removed, and a large amount of remaining scale at the top of the pipeline has not been cleaned, which may cause the pipe top scale to collapse, resulting in pipe plugging and other accidents. Based on this situation, this paper intends to adopt the method of coating tool milling to mill the inner diameter of the pipe to remove the dirt.

After pipeline removal, it often needs spraying. According to the different spray coating materials, spraying can increase the corrosion resistance or wear resistance of the pipeline. At present, some foreign machines and tools have been able to realize the spraying operation in the trench under the condition of pipeline shutdown or non-shutdown, and have matched repair equipment on and under the
trench. However, due to the limitations of excavation conditions and pipe grades, foreign large-scale repair equipment and technology can’t be imported directly, while domestic related equipment has low automation level and slow progress.

Before spraying, in order to improve the bonding strength of the coating and the substrate, the surface of the substrate generally needs to be pretreated, and the commonly used pretreatment method is passive processing. The working fluid used in the processing is difficult to deal with, which is an urgent problem to be solved.[6][7][8][9]

2. DESIGN SCHEME

The pipeline robot mainly includes the following components: milling mechanism, walking mechanism, spraying mechanism and external coating supply device.

2.1. Milling part

The overall structure of milling device is shown in Fig 1.

After long-term use, the inner wall of the pipe will inevitably adhere to something that is difficult or even impossible to remove. When the pipe robot works with the conventional designed milling head, the milling mechanism working in the pipe will often have a cutting failure, or even the machine motor will burn, resulting in the damage of the machine. To solve these problems, we need to design a kind of flexible milling head. When the cutter moves to this position, it can use its own flexibility to avoid the fitting material on the inner wall of the pipe, which can extend the service life of the cutter and make the operation process of the pipe robot more smoothly. In order to achieve the desired effect, the structure design is based on the improvement and optimization of the basic structure of the universal gyroscope. As shown in Fig 2.

![Figure 1. Overall structure of milling device](image-url)
The problems should be considered in the design are the following: 1. How to prevent the twist of the mechanism caused by the cutting force when the cutter is cutting. 2. How to adjust the milling radius of the tool. 3. How to realize the self-adaptive of pipe inner diameter. 4. How to increase the bonding strength with the substrate in the subsequent spraying process without passivation.

Basic structural support is required for the milling device during operation. At the same time, due to the tool rotation of the pipe wall for cutting to produce a greater torque, which will make the whole pipe robot device in the opposite direction of the rotation trend. So we need to design a kind of supporting role, but also has a certain balance of torque role of the wheel or wheel group. In order to solve this problem, this scheme uses six groups of wheels, as shown in Fig. 1. The design of the robot body can achieve a good supporting effect, and at the same time, the torque of the tool borne by each supporting leg is not too large.

Considering the pipe diameter will change in the actual situation, so in the balance wheel assembly using spring, when the pipe diameter is smaller, by compression spring reduce the radius of the wheel.

The second problem is solved by means of a chute. During milling, the milling Cutter Blade can be moved along the inside of the cutter chute to change the radial position of the cutter tip. This position can be adjusted in advance to achieve a certain range of pipe diameter milling.

The third problem is solved by the principle of automatic umbrella. In the back part of the motor, a group walking wheels are designed according to the principle of automatic umbrella bone. When the pipe diameter is large, the Middle Spring bears certain pressure. When the pipe diameter becomes small, the spring is compressed again and tightly fits the pipe inner wall. Because of the triangle supporting principle, the central axis of the whole milling section is roughly distributed in the central location of the pipeline.

The solution to the fourth problem is to use the tool coating structure. This kind of structure can make the pipe surface obtain high peel strength.

2.2. Walking mechanism
The structure of the walking mechanism is shown in Fig. 3. The motor drives the worm gear and worm pair which are meshed with each other at 120° to realize the uniform walking of the robot. Its specific transmission process is: Motor - worm - worm gear - gear - wheel.

The main problem to be considered in this design is how to adapt to different pipe diameters. To solve this problem, we propose the following solution:

The scheme is that the front wheels and the back working wheels distributed in the pipeline are connected by connecting rods, and the wheels are equipped with umbrella shaped brackets to meet the need of different pipe diameters.
2.3. Spraying mechanism
The mechanical part of the spraying mechanism is designed as shown in Fig. 4. Three spray guns are distributed in the circumferential direction for spraying the inner diameter of the pipeline. The spray guns are purchased parts, which act on the telescopic circular pipe and rotate along the circumference. The power is driven by the worm of the traveling mechanism. The length of the four supports can be telescoped to adapt to different pipe sizes, which can be adjusted in advance before spraying. When the spraying mechanism only mills the pipe, it only makes rotation movement, but does not perform spraying actions, and is not connected with the external spraying system.

The main problem to be considered in the design: how to reduce the impact of external spraying system on the robot when milling the inner wall of the pipeline.

The solution is to set the external spraying system as a detachable device, and the external system can be removed during the milling operation.

3. Coating tool

3.1. Tool coating
Coating cutter is a new type of cutter which has appeared in recent 20 years. It is an important breakthrough in the development of cutter. It is an effective measure to solve the contradiction relation among hardness, wear resistance, strength, toughness and so on.

Different coating and substrate materials have different effects on cutting process and cutting tools. When designing coated cutting tools, it is necessary to design appropriate coated cutting tools according to the requirements of machined parts, including hardness, strength and related special needs.

The base material of the cutter should have certain hardness and plating ability. Because the cutting part of the material of original milling cutter is generally diamond, and the surface of the diamond material itself can not be modified, so the first need to change the base material of the cutter. On the one hand, the substrate layer has a certain degree of hardness, on the other hand, it can be more convenient for coating on the surface.

Considering synthetically, the base material layer made by blending styrene propylene copolymer and silicon carbide fiber has the characteristics of high hardness and high strength, and the most
importantly is that its surface can be modified and some cement layer or wear-resistant coating can be sprayed or sputtered, which can be helpful to improving the cutting ability of milling cutter. Therefore, the material of the substrate layer is selected as the blend of styrene propylene copolymer and silicon carbide fiber.

The coating material needs to have a certain hardness, and can remain on the surface of the object in the milling process. Therefore, the hardness of the external coating should be moderate and not too high, so that the surface of the external coating can produce some losses when it is cut rapidly, and the coating with these losses is left on the surface of the embryo, which has the effect of similar sealing agent and passivation agent, and has an impact on the roughness and chemical modification of the surface of the embryo.

The treatment ability of the outer coating to the cutting surface is similar to the passivation treatment, i.e. the raw material cut by the milling cutter can be directly coated with coating without passivation treatment before coating. In the process of contact between the milling cutter outer coating and the blank, the surface structure of the blank is affected, which makes the coating on the blank surface have a certain adhesion. The coating materials are alumina, barium oxide, zirconia, boron oxide and lanthanum hexaborate.

The manufacturing of the whole cutting tool can be realized by the following methods: first, the styrene propylene copolymer is hotly melted, and then the SiC fiber is added and blended to obtain the base material layer. The outer coating can be applied on the substrate layer by arc spraying.

The experimental design of the coated tool is carried out according to the above scheme.

3.2. Base materials
The substrate layer includes the following materials: 100 parts of styrene propylene copolymer, 20-25 parts of silicon carbide fiber, each part represents a standard weight.

Under the polymerization condition of polypropylene, styrene propylene copolymer can be obtained by mixing styrene monomer and propylene monomer in proportion. The ratio of styrene monomer and propylene monomer is not limited, because it is found that the difference of the ratio of the two monomers has little effect on their application. The average weight of molecular styrene propylene copolymers can be between 20000-100000g/mol. SiC fiber is used to increase the hardness and high temperature resistance of styrene propylene copolymer.

3.3. Outer coating materials
The outer coating includes the following materials: alumina 100 parts; barium oxide 40-42 parts; zirconia 10-12 parts; boron oxide 6-8 parts; lanthanum hexaborate 2-3 parts, each of which is standard in weight.

Alumina and barium oxide are the main materials, which are mainly used to control the hardness of the coating; zirconia is used to adjust the peeling speed of the coating during cutting; boron oxide and lanthanum hexaborate are used to improve the sealing performance of the coating on the surface of the blank after peeling. The base material layer also includes 4-8 parts by weight of poly (lactide). The number average molecular weight of poly (lactide) may not be limited to 20000-50000g/mol. Poly (lactide) is used to increase the adhesion of composite ceramic coating to improve the structural stability of milling cutter.

In order to make a comparison, different material proportion schemes are carried out for the coating, and schemes 1 to 10 are proposed. The difference of different schemes is mainly due to the different kinds and weight of the base material layer and the outer coating material.

The coating of scheme 5-10 increased 2-3 parts of calcium titanate by weight compared with scheme 1-4. Calcium titanate is used to reduce the sputtering radius of the milling cutter outer coating peeling off during cutting, so as to improve the operation accuracy of the milling cutter to the blank and increase the uniformity of the surface treatment of the blank.

Compared with scheme 5-10, scheme 7-10 added 2-3 parts of bovine bone powder. Bovine bone powder is used to increase the bonding strength of the embryo material and the subsequent coating
after milling.

The coating of scheme 9-10 also includes 2-3 parts by weight of strontium carbonate. Strontium carbonate is used to increase the bending strength and toughness of the preform after milling and the subsequent coating.

3.4. Scheme implementation
In order to observe the influence of the above 10 schemes on the tool performance, change the weight of the material without changing the material composition of the tool in the scheme, as shown in Table 2. The results reflect the peel strength of the steel plate surface under each scheme.

3.5. Scheme comparison
Taking the 1.2mm thick steel plate (GB2517-81) as an example, the groove is milled on an area of 0.5m × 1m, and the groove length × width × depth = 1m × 1cm × 0.5mm. After the groove is milled in the scheme of this plan, roll coating is applied directly, and then dried to detect the peeling strength of the coating (Table 3). The coating is polyurethane coating (s52-40 type).

Table 1. Specific composition of base material layer and outer coating material under different schemes

| Substrate layer | scheme 1 | scheme 2 | scheme 3 | scheme 4 | scheme 5 | scheme 6 | scheme 7 | scheme 8 | scheme 9 | scheme 10 |
|----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| Styrene propylene copolymer (a set) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Silicon carbide fiber (a set) | 20 | 25 | 20 | 25 | 20 | 25 | 20 | 25 | 20 | 25 |
| Polylactide (a set) | 0 | 0 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 |

| Outer coating | scheme 1 | scheme 2 | scheme 3 | scheme 4 | scheme 5 | scheme 6 | scheme 7 | scheme 8 | scheme 9 | scheme 10 |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| Alumina (a set) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Barium oxide (a set) | 40 | 42 | 40 | 42 | 40 | 42 | 40 | 42 | 40 | 42 |
| Zirconium oxide (a set) | 10 | 12 | 10 | 12 | 10 | 12 | 10 | 12 | 10 | 12 |
| Boron oxide (a set) | 6 | 8 | 6 | 8 | 6 | 8 | 6 | 8 | 6 | 8 |
| Lab_6 (a set) | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 |
| Titanat (a set) | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 3 | 2 | 3 |
| Bovine bone meal (a set) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 3 |
| Carbonate (a set) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 3 |

Table 2. Peeling strength of milling surface under different schemes.

| Peel strength(N/m) | scheme 1 | scheme 2 | scheme 3 | scheme 4 | scheme 5 | scheme 6 | scheme 7 | scheme 8 | scheme 9 | scheme 10 |
|--------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| 3.01 | 3.02 | 3.12 | 3.10 | 3.13 | 3.13 | 3.35 | 3.36 | 3.38 | 3.37 |

Table 3. Peel strength of passivation and non-passivated surfaces

| Coating obtained without passivation | Peel strength(N/m) |
|-------------------------------------|---------------------|
| Passivated coating                  | 1.77                |
|                                     | 3.14                |
It can be seen from the above tables and figures that the peel strength of the coating tool basically reaches the strength of the passivated coating.

4. WORKING PRINCIPLE
After the components are assembled, the model is shown in Fig. 7.

Working action of robot: Firstly, the milling of the pipe is carried out, and the robot is driven in the pipe by the motor of the walking part, and there are walking wheels and supporting wheels in the front and back of the robot. The milling mechanism adjusts the cutter position according to the pipe radius in advance. After milling, a layer of material remain on the inner surface of the pipe due to the action of tool coating. After cleaning the dirt inside the pipe, remove the whole milling mechanism. Connect the external spraying system to carry out the spraying work of the pipeline, and still drive the robot through the moving parts. The three airbrushes installed on the spraying pipeline can rotate to complete the spraying action of the inner diameter of the pipeline. In order to reduce the influence of the running parts on the sprayed surface, the spraying mechanism is at the back of the moving direction to avoid the damage of the wheel to the sprayed surface.
5. CONCLUDING REMARKS
At present, the existing pipeline robots have few models in cleaning and spraying, especially the pipeline spraying robots. There is no combination of the two forms, so this kind of robot has a high cost performance ratio. In addition, this kind of robot can clean and spray the pipeline without considering the storage and treatment of acid wash solution and passivation solution, which is beneficial to the environmental protection. In this design, considering the life of different components, a combined form is adopted. It can be seen that the performance of the device is far better than that of the existing devices on the market.

REFERENCES
[1] Zeng Junde, sun liangbo, Gong Junjie, Liang Huiyong and Guo Chengcheng. “Innovative design of complex pipeline cleaning robot structure,” Robotics, 2018, pp.35-38.
[2] Li Jianguo, Li Wei and Wang Chengjun. “The design of the robot for descaling the ash pipeline of coal-fired power plant,” Water conservancy and electric machinery,2017, pp.22-23.
[3] Li Rongguang, Hao Xianguo, Wu Changyi and Tang bin. “Development and application of pipeline automatic spraying machine ,” Oil and gas storage and transportation, 2009, pp.58-65.
[4] Chen Tianyu. “Stainless steel surface treatment technology”, Chemical Industry Press, Beijing, 2016, pp.120-180.
[5] Nian sicheng,Deng Zhongliang and liu Tie. “Structure design and performance analysis of a pipeline robot,”Machinery Design & Manufacture, 2019, pp.253-255+260.
[6] Zhu Zeze. “Application of stainless steel and its surface treatment and processing technology, ” Special steel technology, 2014, pp.8-13.
[7] Wu Yang. “Analysis of stainless steel application and surface treatment technology, ” China Equipment Engineering, 2017, pp. 105-106.
[8] Chi Shoujuan and Huang Shouchun. “Process research on improving surface quality of stainless steel equipment,” Guangzhou chemical industry,2014, pp. 117-119.
[9] Shao zekuan. “Current research on coated cutting tools, ” Science and engineering of non-ferrous metals,2017, pp. 57-64.