Mechanical Fault Diagnosis and Repair of the Mobile Robot
Based on "Four Diagnosis Methods"

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Abstract. Aiming at the relatively simple electromechanical devices such as mobile robots, a specific operation procedure of the mechanical fault diagnosis method was designed based on the "Four Diagnosis Methods" practiced in ancient Chinese medicine. In the mobile robot, for example, the human "eyes, ears, mouth, hands," and other sensory organs are firstly used for information collection, followed by the human brain for information processing, where fault diagnosis counts on professional knowledge and experience to carry out fault management. The results show that this methodology is simple, efficient and convenient in mechanical fault diagnosis.

Introduction
Mobile robot is a comprehensive system integrating environment perception, dynamic decision and planning, behavior control and execution [1-3]. It represents one of the most active areas in the development of science and technology combining with multi-disciplinary research results, such as mechanical design and manufacturing, sensor technology, information analysis and processing, electromechanical engineering, automatic control and artificial intelligence. Owing to continuous improvement in the performance, mobile robot has its application range being greatly expanded. More than in the industrial, agricultural, medical, services and other industries, amazing benefits are also widely witnessed in urban safety, national defense and space exploration and other hazardous and dangerous occasions [2, 4, 5].

In the use of the robot, timely fault diagnosis and management, maintenance and care can be truly beneficial for going to an extra mile in efficiency and service life [6-8]. Especially, the popularization of computer technology comes with the advancement of intelligent science and technology, where the fault diagnosis technology has gradually developed into an emerging marginal integrated engineering discipline, which has been drawing more attention of the enterprises and government departments.

As we all know, there are numerous reasons that may lead to failure, and fault types vary. When it comes to the location where the faults may be present, the faults can be simply divided into two categories: the mechanical and electrical faults. For mechanical failure, the TCM-based traditional fault diagnosis method featured by "Look, Listen, Query, Touch" is still the most widely used approach of the utmost practice. "Look, Listen, Query, Touch," the so-called "Four Diagnosis Methods", was originally summarized by Bian Que, a prestigious physician in the ancient Chinese Warring States Period, according to the folk experiences and his own medical practice in the diagnosis of diseases. "Four Diagnosis Methods" marked great achievements in medical applications [9, 10]. And in teaching management and fault diagnosis, it has also achieved fruitful results. Remarkably, impressive performance has been exhibited in economic reconnaissance and intelligence gathering.

Methods
Equipment fault diagnosis is technologically performed in three steps: information acquisition, analysis and fault diagnosis. First of all, the human eyes, ears, hands and mouth and other sensory organs are engaged for information collection, and then the brain takes over the job to analyze and
deal with information. Subsequently, knowledge and experience are utilized for fault diagnosis, and finally, provide decision support for troubleshooting.

Machinery structures similar to the mobile robot is a relatively simple equipment, which may use specific operational processes designed in this work based on "Four Diagnosis Methods", as shown in Fig.1.

**Case Study**

**Diagnostic Objects**

The omnidirectional mobile robot, developed by Prof. Chen Shanpeng of Japan's Mie University, adopted a new wheel-tread compound structure, which can realize all-direction autonomous movement with zero-turning radius in unstructured environments, as shown in Fig.2.

The robot is equipped with 4 sets of travel components, which are driven independently by 4 motors, and can realize omnidirectional walking by adjusting the output of each motor. At the same time, the use of the wheel structure, improved the obstacle ability and climbing ability of the robot. During the course of the movement, the robot may also achieve a certain degree of posture reconstruction by hinge connection to adapt to different road conditions.

**Information Collection**

The use of "Four Diagnostic Methods" for information acquisition is the premise of a mobile robot on mechanical fault diagnosis.

Look: When the traveling parts on the both sides of the east and the west are used as the driving members, the power transmission is interrupted at the traveling part of the east side, and the chain may appear fall off on the west side.

Hear: During the movement of the robot, the noise is large and the sound of the rubber wheel touching the road surface is clear. Intermittent dry and harsh friction sound is heard.

Touch: When the robot is running, touches the robot to feel that the whole body vibration is very obvious; on the bevel gear shaft, a torsional vibration touch is also very significant, while the motor surface temperature presents no significant change.

Figure 1. Mechanical fault diagnosis - specific operational processes.
Query: Ask the person concerned to learn that the robot has not been used and maintained for a long time. Until recently, the mechanical parts of the robot have been dismantled, cleaned, assembled and commissioned.

**Analysis and Treatment**

Robot power transmission depends on the elastic coupling from the motor shaft to the bevel gear shaft, from which transmission comes through the bevel gear to the sprocket shaft, and finally to the sprocket, as shown in Fig.3.

In power supply, check the power transmission link on the side of the fault and find that the power is not transmitted from the bevel gear shaft to the bevel gear. The problem arises in the connection between the bevel gear shaft and the bevel gear. After disassembly, it was found that between the end face of the screw used for fixing the connection and the surface of the shaft was a point contact, and the compressive stress was too great, resulting in a slip phenomenon among the power transmission process, as shown in Fig. 4.

In general, the main reason for the chain to take off from the sprocket is that the chain tension is not enough, or the installed position error between the sprockets is too large. The inspection found that: on the failure side, the three load-bearing wheels did not share the same plane with the main and driven wheel installation datum, causing the position degree of a serious over-tolerance; and the tension mechanism rigidity was not enough, the installation position of the tension wheel was unable to be properly maintained in the running process, as shown in Fig. 5. And the machining accuracy of parts was not high enough for the installation being completely interchangeable, so that the motor shaft and the bevel gear axis had serious over-tolerance in terms of concentricity error.

The inspection also found that: the bevel gear seat and mounting base plate were placed without the use of positioning components, only relying on two screws. During power transmission, there must be some looseness between bearing seat and mounting plate. Polygon effect is the main reason for robot vibration, yet this is the inherent characteristics of the ordinary chain drive, and there is no way to eliminate it. Additionally, the rubber wheel group was fixedly connected to the chain at equal intervals, and the rubber wheels were not always in contact with the ground in the waking state, which also exerted the polygonal effect to a great extent.
Fault Mechanism

The root cause of the power transmission interruption was that the contact area between the end surface of the fixing screw and the outer cylindrical surface of the bevel gear shaft was too small. According to the principle of compressive stress, a certain compressive stress may be reduced by increasing the bearing area.

The main reason for the chain falling off during the robot walking was that the position error between the sprockets was too big and the rigidity of the tensioning mechanism was not enough. According to the error generation mechanism and the mechanical strength theory, the installation error of the sprockets can be reduced by adjusting the installation positions of the sprockets, and the overall rigidity of the tensioning mechanism can be improved by adding the auxiliary elements or replacement stronger parts.

According to the six-point positioning principle, under-positioning is one of the root causes of component failure, which should be avoided in the design. Therefore, a positioning element can be fitted between the bearing seat and the mounting plate to ensure that the robot remains in the correct position during operation.

In addition, increasing the contact area between the rubber wheel and the road surface in the advancing direction may also alleviate the polygonal effect.

Troubleshooting

There are two ways to increase the contact area between the end surface of the fastening screw and the outer cylindrical surface of the shaft: first, the end surface of the fastening screw is changed from plain to circular surface, and second, the relevant part of the outer cylindrical surface of the shaft is made up on a plane. Economically, the parts processing made it clear that the latter is more feasible. The specific circumstances of bevel gear before and after the improvement are shown in Fig.6. As the locating element, the cylindrical pin is the most widely used between the bearing seat and the mounting base. In the bearing seat and the installation underside, a hole in exactly the same size and accuracy was processed, respectively, and interference fit was given between the holes and the cylindrical pin to ensure that during the power transmission the correct installation location was always maintained, as shown in Fig.7.

![Figure 6. Repairs of Bevel Gear Shaft.](image)
![Figure 7. Repairs of Bearing Seat and Installation Plate.](image)

To improve the rigidity of the entire tensioning device, the tension adjustment blots (as shown in Fig.5) were replaced, these blots size from the 4mm increases to 5mm. After replacement, the stiffness increased by 67%.

Under the premise of no motion interference, it is effective to reduce the polygonal effect of the chain drive by optimizing the installation distance between the rubber wheel groups, as shown in Table 1. After adjustment, the vibration amplitude of the polygonal effect was reduced by 27%.

| Table 1. Rubber Wheel Sets - Installation Spacing Adjustment. |
|--------------------------------------------------------------|
| Before adjustment | After adjustment |
|-------------------|------------------|
| Installation spacing | 75mm | 62.5mm |
| Number of rubber wheel sets | 7 | 8 |
| Vibration amplitude | 21.78mm | 15.88mm |
Conclusions

Through the diagnosis and repair of the two kinds of mechanical faults, such as power transmission and moving gait of a mobile robot, the research work in this paper has made the following progresses:

(1) Design and implementation of the specific operational processes based on “Four Diagnosis Methods” for the mechanical fault diagnosis. By the use of eyes, ears, mouth, hands for fault information collection, the cause of the failure may be identified to work out the fault mechanism as the premise for fault diagnosis.

(2) The important effect of fault repair principle on repairs result was demonstrated. Determination of the fault repair principle inevitably involves many practical conditions, such as repair costs, duration and technical feasibility, etc. Mechanical failure may not always be completely repaired, but can be effectively managed.

(3) The main mechanism of mechanical failure and repair methods were summarized. Mechanical failure is mainly caused by parts damage, as well the processing accuracy and installation accuracy, over-tolerance of spare parts, as well as their inherent design flaws. In view of the above, repair manuals may include parts replacement, repair & adjustment, and re-design and so on.

In addition, the fault diagnosis may also show the way for the subsequent improvement of the device design. For example, the walking fault caused by the polygon effect caused by the ordinary chain transmission, to replace the ordinary chain with tooth chain will be an important aspect of the structure improvement.

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