A Robot for Welding Repair of Hydraulic Turbine Blade

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***Abstract*—This paper proposed a scheme of using rail-free multifunctional robot in onsite repair of hydraulic turbine blade for large-scale axial-flow and Francis runners. The robot processes such functions as profile detection and measurement, air-gouging cleaning, grinding, welding and so on. The robot’s main body is composed of an all-position rail-free mobile platform and a multiple degree-of-freedom (DOF) manipulator. The mobile platform, on which the manipulator equipped with all kinds of exchangeable operating tools is mounted, adheres to the surface of the hydraulic turbine blade to be repaired. The operator can control the robot to carry out repairing work automatically through man-machine conversation interface of a monitoring system. Simulation of the process of welding repair using the robot was conducted. And prototypes of key components of the robot system were developed. Preliminary experimental results proved the feasibility of scheme of the repairing robot.**

***Keywords*—rail-free robot, hydraulic turbine blade, onsite repair**

I. Introduction

Hydroenergy is one of the clean and renewable energy that can be most widely used today, and to utilize water power in large scale is of great importance[1]. As the power generating machine, hydraulic turbine plays a great role in the utilization of water power. When being used hydraulic turbine blade would subject to such damages as cavitation damage induced by the passage of water as well as erosion damage caused by sand contained in the water as shown in Figure 1, and the damages make the power-generating efficiency decrease and vibration of the hydraulic turbine aggravate, and sometimes the hydraulic turbine has to be turned off because of large amount of leakage[2]. To ensure that the hydraulic turbine run safely and stably, hydropower station has to maintenance and repair the hydraulic turbine regularly.

The general course of repairing hydraulic turbine blade is as following[3,4]: (1)determine the area that needed to be repaired;(2) clean up the area using such methods as air gouging and grinding;(3) repair welding;(4) grind the welded area according to the original shape of the hydraulic turbine blade’s surface;(5) profile measurement and flaw detection of the blade surface repaired;(6) spray coating if necessary.

According to where the operation is carried out, repair of the hydraulic turbine blade can be classified into two types: on-site repair and off-site repair. When off-site repair is carried out in advance, the hydraulic turbine runner has to be hanged out of the pit, which is cumbersome and time-consuming. To overcome the deficiency of off-site repair, on-site repair is put forward, which means the operation is carried out right in the pit where the hydraulic turbine is installed. On-site repair has the following characters: (1) All-position operation. For example, when repairing blades of Francis hydraulic turbine runner (shown in Figure 2), the welding operation is always vertical welding or horizontal welding, but when repairing blades of axis-flow hydraulic turbine runner (shown in Figure 3), the welding operation is mainly downhand welding or overhead welding. (2) The repairing sequences being complex: the repair of the hydraulic turbine blade includes such operations as gouging cleaning, welding, grinding, measurement and coating, which makes the repair complex and difficult. (3) The space left for repair being small and the working environment being formidable. Take the repair of the Three Gorges Hydro-power Station’s hydraulic turbine blades in China as the example, the minimum distance between the blades of the hydraulic turbine is as small as 400 mm.

(a) Erosion (b) Cavitation
Figure 1. Damages of hydraulic turbine blade.

Figure 2. Francis runner.

Figure 3. Axis-flow runner.

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The amount of labor of repairing being large, the working condition being formidable, the repairing efficiency being low, and the repairing quality can not be guaranteed, and all these make the automation of on-site repair of hydraulic turbine blade necessary.

The Scompi series robot 345 co-designed by the research institute of Hydro-Québec and Invensys of Canada is the only equipment that can repair hydraulic turbine blade automatically on site around the world so far[5]. The Scompi robot is a track-based, six-axis, multi-process robot[6]. The robot has excellent welding ability and can perform precision grinding. The robot can be remote-controlled through a pendant[7]. But the Scompi robot has one main deficiency: the robot is rail-guided. So during the course of repair, the rail has to be installed and demounted repeatedly according to the position of the damage, and this makes the repairing efficiency decrease. And especially in some position, the rail can not be installed at all because the curvature of the hydraulic turbine blade's surface is too small or the space is too tight, thus the work space of the robot is limited.

The purpose of this paper is to introduce a new scheme of an on-site hydraulic turbine blade repair robot based on rail-free mobile platform, and simulation and preliminary experimental results of the robot are also presented.

II. RAIL-FREE ROBOT FOR ON-SITE WELDING REPAIR OF HYDRAULIC TURBINE BLADE

A. Function and Composition of the Robot

To overcome the deficiency of current automatic hydraulic turbine blade repair devices, the scheme of using rail-free robot in the on-site welding repair of hydraulic turbine blade was put forward.

The function of the on-site rail-free robot for welding repair of hydraulic turbine blade is illustrated in Figure 4, which can be summarized as: the robot can move on all position of the hydraulic turbine blade's surface freely, the robot can carry out onsite measurement of the damage status of the hydraulic turbine blade, and the operator can control the robot to perform such repairing tasks as air gouging, repair welding, grinding and so on through the man-machine conversation interface of the monitoring system automatically.

The composition of the rail-free robot is illustrated in Figure 5. The system can be divided into two parts: one part on the hydraulic turbine blade and the other part off the hydraulic turbine blade. The part on the hydraulic turbine blade includes rail-free mobile platform, the platform adheres to the surface of the hydraulic turbine blade by the sucking force provided by adhesion devices. A multi-DOF manipulator is mounted on the mobile platform, and such devices as laser distance measuring instrument, monitoring cameras, and illuminating lamp are fixed on the end of the manipulator, and at the same time the manipulator carries exchangeable tools of the operating system (air-gouging system, welding system, grinding system) and other necessary accessories. The part off the hydraulic turbine blade mainly includes power supply, remote controller and the main controller. The two parts are connected and communicate through electric cable.

B. Rail-free Mobile Platform

The key of the onsite welding repairing robot is the development of rail-free mobile platform. The platform needs no track, so the work scope of the robot is much increased compared with the Scompi robot. And the elimination of the work of installing and dismantling the track makes the repairing work easier and greatly boosts the productivity.

The principle scheme of the rail-free mobile platform is illustrated in Figure 6. To improve maneuverability, the platform adopts wheeled moving mechanism. Since the blade is made up of ferromagnetic material, the platform uses permanent magnetic adhesion devices to provide the sucking force needed according to the payload. To decrease the moving resistance of the platform, the magnetic devices are non-contact with the surface of the hydraulic turbine blade and a gap existing between them.

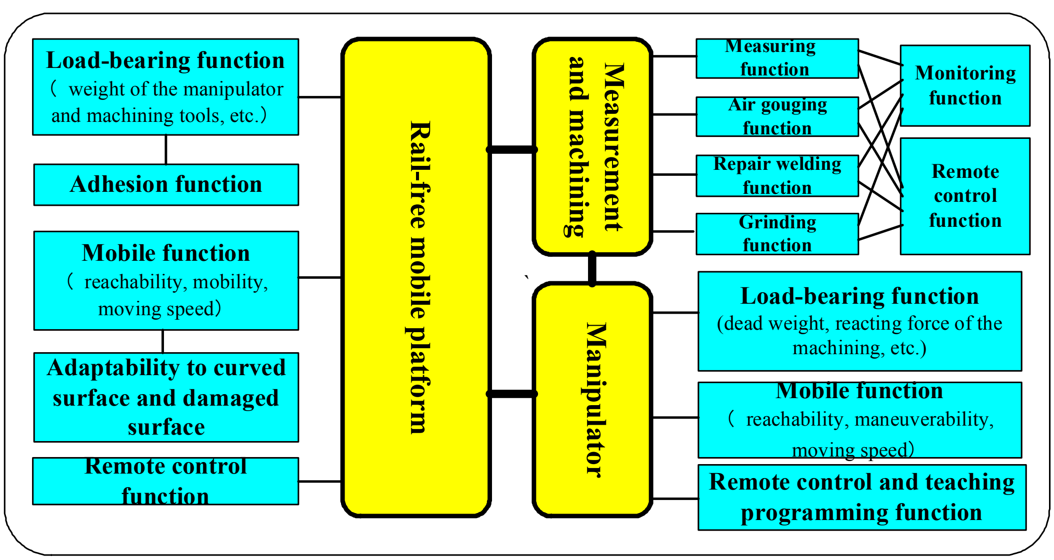


Figure 4. Function of the robot.

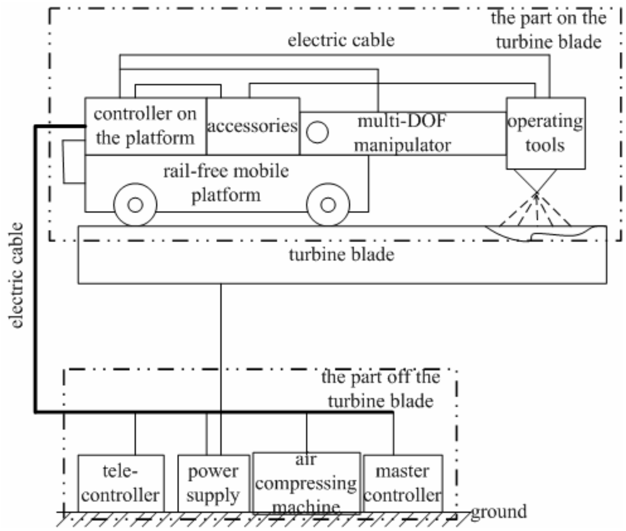


Figure 5. Composition of the robot.

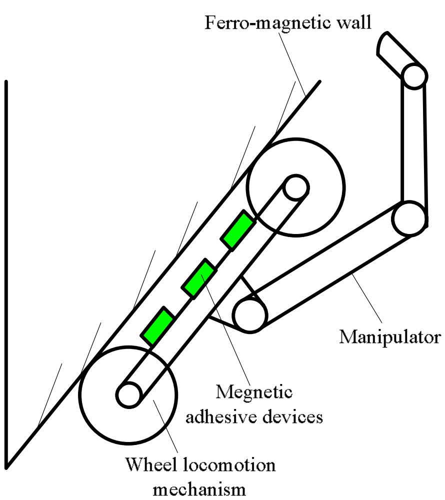


Figure 6. Principle scheme of the platform.

III. PROCESS FLOW FOR ON-SITE WELDING REPAIR

The process flow of on-site welding repair of hydraulic turbine blade based on rail-free robot is illustrated in Figure 7. Firstly set up ladder and scaffold below the hydraulic turbine runner, then put the rail-free mobile platform with manipulator and devices of measuring and monitoring installed on the hydraulic turbine blade's surface to be repaired with proper tools.

And when repairing the hydraulic turbine blade the operator can see the following items on the monitoring screen: (1)Position and posture of the robot on the hydraulic turbine blade, based on which the robot can traverse the hydraulic turbine blade's surface to determine the area to be repaired ; (2) Simulation of current position and posture of the manipulator, then the operator can tele-control the manipulator; (3)Real-time images of the actual state of the area near the end of the manipulator, based on which the operator can determine how to repair the damaged area, thereafter the operator can remote-control the robot system to carry out repairing operation. And all these operations are carried out with the help of the man-machine interface of the monitoring system.

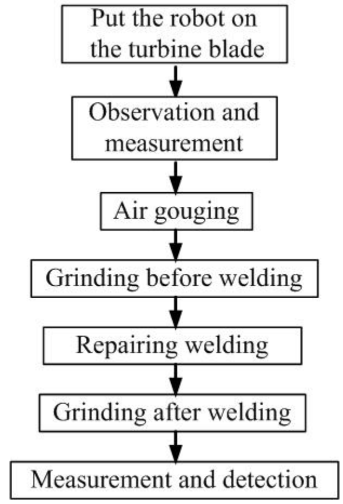
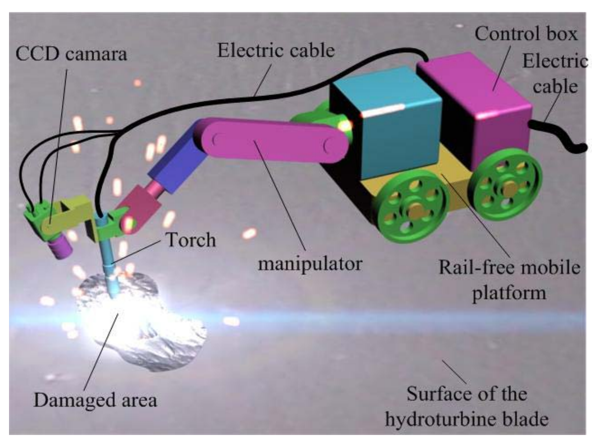


Figure 7. Process flow of on-site welding repair.

IV. SIMULATION OF THE PROCESS OF WELDING REPAIR

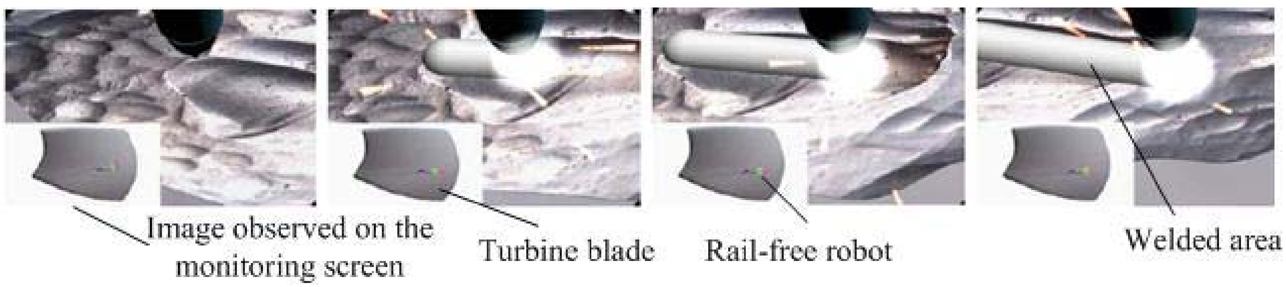
Simulation of the repairing process of the hydraulic turbine blade has been done, for instance, the process of the repairing weld is illustrated in Figure 8. Figure 8a shows the configuration of the part of the robot system on the hydraulic turbine blade when welding, Figure 9b are the images of the welding process, and Figure 8c shows the area being welded and the robot's position on the hydraulic turbine blade's surface observed on the monitor.

Take the repairing weld as the example to illustrate how to manipulate the robot, which is illustrated in Figure 9. Firstly the robot scans the profile of the hydraulic turbine blade and search the damaged area; when the damaged area is found, measurement is carried out, based on which the machining path is created; then repairing weld is carried out automatically; after the repairing weld completed, the robot measures the area again to determine whether the area needed to be welded any more. If the answer is yes, repairing weld will be implemented on the area for the second time until the area is repaired completely. If not, the robot will move on and search another area needed to be repaired.



(a) Configuration of the robot

(b) Images of the welding process



(c) Images observed on the monitoring screen

Figure 8. Simulation of the process of the repairing weld.

(a) Search the damaged area (b) Measure the flaw and programming (c) Repairing weld (d) Measure the welded area

Figure 9. Simulation of the process of manipulating the robot.

V. PRIMARY EXPERIMENTAL RESULTS

The rail-free robot that has been developed includes rail-free mobile platform, manipulator, machining tools and other necessary accessories, and the total mass of the robot is about 50 kg, and the whole dimension is 600 mm×400 mm×100 mm or so. The prototype of the mobile platform (Figure 10) and the manipulator (Figure 11) have been manufactured, the measuring system utilizing laser distance-measuring equipment and CCD has been developed, and experiments of the repairing process has also been conducted (Figure 12).

Key parameters of the rail-free mobile platform are listed in Table 1. Experimental results show that the mobile platform has a large load-bearing ability, small turning resistance, excellent mobility (especially the turning mobility) and satisfactory complex spatial curved-surface self-adaptation capacity, whose performance is much improved compared to similar traditional mobile platform.

The manipulator developed has 7 DOFs with the total height 240 mm, the total length 560~660 mm and the total weight about 20 kg. Experimental results show that the manipulator can bear tangential counterforce up to 200 N and normal reaction up to 400 N, and can carry repairing tools (i.e. measuring tool, air gouging gun, welding gun, grinding tools) to conduct repairing work such as measurement, air gouging, welding and grinding.

Primary experimental results prove that the robot can reach more than 90 percent of the surface area of the hydraulic turbine blade and the repairing scheme is feasible.

VI. ADVANTAGES OF USING RAIL-FREE ROBOT

The rail-free robot provides the following benefits when being used in hydraulic turbine blade repair:

1) Facilitates on-site maintenance and repair of hydraulic turbine blade, boosts the productivity greatly while dramatically reducing repairing defects and improving the repairing quality;

2) Reduces repair time. Thanks to its compact size and modular components, the robot system can be easily installed in tight work spaces, so the hydraulic turbine blade can be repaired on-site, which saves precious time for dismantling and installation of the hydraulic turbine runner. And the system needs no track, which greatly increases the reach of the repairing operation and eliminates the work of installing and dismantling the track.

3) Improves the working environment for operators, who must still monitor the task, but are spared continuous exposure

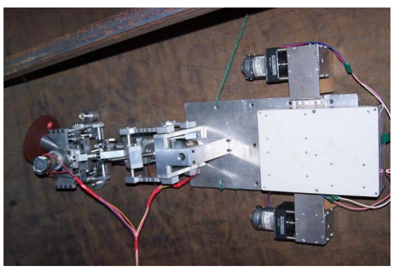
to toxic fumes and burning projections and the demands of awkward working positions;

4) Works in environments not conducive to humans, such as tight spaces and radioactive areas.

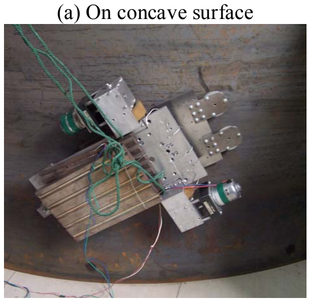
VII. CONCLUSION

This paper proposed a scheme of using rail-free robot in on-site welding repair of hydraulic turbine blade for large-scale axial-flow and Francis runners. The function and composition of the rail-free robot were illustrated. The process flow of the welding repair was then discussed and key parameters of the robot system were presented. Thereafter simulation of the process in welding repair of the hydraulic turbine blade was carried out. Simulation and preliminary experimental results show that the scheme is feasible and implement of the scheme will automate on-site repair of hydraulic turbine blades to increase the productivity and quality of the repair and to improve the health and safety of workers.

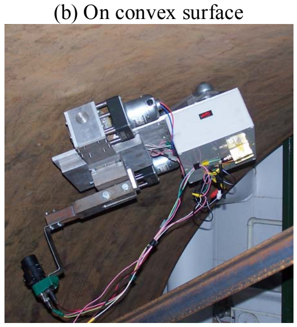
And future work including integration and optimization of the robot system is essential so that the robot can be used on site.



(a) On concave surface



(b) On convex surface



(c) On surface of negative slope

Figure 10. Mobile platform running on three typical surfaces.

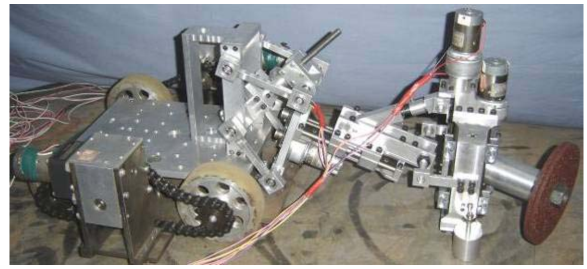


Figure 11. Prototype of the manipulator.

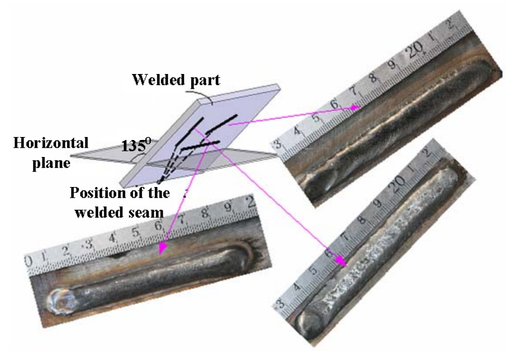


Figure 12. Results of all-position MIG welding experiments.

TABLE I. KEY PARAMETERS OF THE RAIL-FREE MOBILE PLATFORM

Characteristics	Numerical value
Payload	80 kg
Wight	30 kg
Dimension	600 mm×400 mm×100 mm
Speed	1 m/min
Minimum turning radius	0
Minimum curvature radius of the surface on which the platform can run	1.5 m

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