Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P1-27

A STUDY ON ULTRA-HIGH PRESSURE WATER JET WALL CLIMBING ROBOT FOR REMOVAL RUST IN VESSELS

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ABSTRACT

In this paper a Ultra-high pressure (UHP) water jetting removal rust cleanout auto-robot is designed, which works with the high-pressure pump units with pressure 250MPa and the vacuum residue displaced system. It is the implement machine for the removal rust system. Three key technique questions are solved in the cleaning automation process. These are wall attaching, wall moving and wall cleaning technique. Experiments showed that the robot both remove rust efficiently and move agility.

KEY WORDS

Removal rust, Wall-climbing robot, UHP water jetting

NOMENCLATURE

d : nozzle diameter
F_f : water jetting kick force
F_m : each permanent magnet adsorption affinity
F_{max} : maximal water jetting kick force
F_{m1} : the first permanent magnet adsorption affinity
F_S : vacuum suction force
G : the total gravity of robot and its load
H : the distance between gravity center and vessel wall
h : the distance between adsorption affinity and holding power in a permanent magnet
l : the distance between first and mid magnet
l' : the distance between first and last magnet
M_A : the total tip-back torque of point A
M_f : the total torque from resisting force in a magnet
M_G : the torque from gravity
M_Q : the torque from motor output by reductor
N_i : holding power of each permanent magnet
N_1 : the first permanent magnet holding power
n : the number of permanent magnets attaching wall
P : vacuum pressure
p : jetting pressure
q : flux
r : working radius
a : included angle between vessel wall and gravity
β : water jetting direction change
μ : friction factor between vessel wall and robot
ρ : density of water
v : speed of water jetting

INTRODUCTION

Water hydraulics has advantages of environmental friendly, cleanness, safety, readily available, inexpensive, and easily disposable[1]. Ultra-high pressure (UHP) water jetting has wide apply. As is shown in Figure 1, a UHP water jetting removal rust cleanout system worked by an auto-climbing-robot is designed. In the system three subsystems are established. They are the high-pressure pump units with pressure 250MPa and power 132kW, the attaching automatically robot system, and the vacuum residue displaced system.

The robot which works as mobile platform and working platform includes two pedrails with some permanent magnets for suction and a combined cleaning device can flush, scrub, scrape the wall surface and collect sewage automatically. It works with water jetting pressure about 250 MPa and can be manipulated by hand-holding control-box remotely.

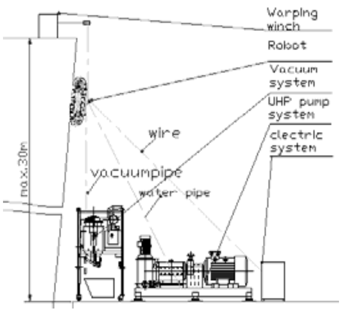

Figure 1 Ultra-high pressure (UHP) water jetting removal rust system

DESIGN INDEX

(1) Max speed : 46.3mm/s
(2) Clambing height : 30m
(3) Rust width : 250mm
(4) Weight : less than 90kg
(5) Degree of vacuum:-0.6bar
(6) Working pressure : 250 MPa
(7) Load ability : 800N

The structure of the attaching robot is design as shown in Figure2. It is driven by two motors that connected with each reductor, and attaching by two pedrails with 72 permanent magnets. A cleaner with nozzles is set in the center of the robot.

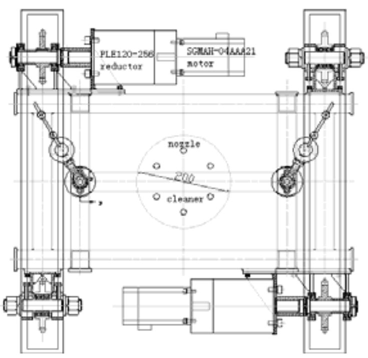

Figure 2 The structure of the robot

THE STATICS ANALYSIS

Considering the operation requires the robot to bear a large load and to be highly reliable, the structure of wall-attaching based on two caterpillar chains with permanent magnets. It is indispensable that the attaching force can overcome the force that arise from robot gravity, load of water canal, air pipe and electric cable, and friction force which arise from vacuum suction[2]. There are water jetting kick force and vacuum suction force act on the robot at work. Their equation are shown in Eq(1) and Eq(2) [3].

$$F_f = 0.745q \cdot \sqrt{p} \qquad (1)$$

$$F_s = \pi \cdot r^2 \cdot P \qquad (2)$$

The robot working platform is not only vertical, even slope. The attaching robot analysis of force in normal vessel wall is shown in Figure 3

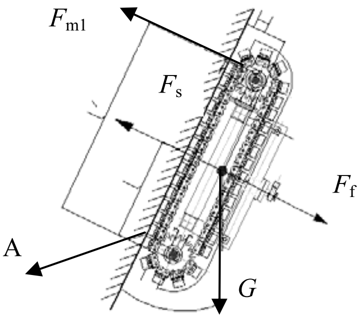

Figure 3 Robot stressed analysis

Gliding analysis

The analysis of force in direction parallel to vessel wall give the no gliding condition in Eq(3):

$$G \cdot \cos\alpha \le F_f \qquad (3)$$

$$F_f = \sum_{i=1}^{n} N_i \cdot \mu \qquad (4)$$

Considering the water jetting kick force and vacuum suction force, the holding power of each permanent magnet is shown in Eq(5):

$$N_i = F_m - \frac{G\sin\alpha + F_f - F_s}{n} \qquad (5)$$

$$\sum_{i=1}^{n} N_i = n(F_m - \frac{G\sin\alpha + F_f - F_s}{n}) \qquad (6)$$

$$F_f = \mu \cdot (nF_m - G\sin\alpha - F_f + F_s) \qquad (7)$$

By means of analyse the robot with water jetting kick force and vacuum suction force, the condition of no gliding is shown in Eq(8):

$$F_m \geq (\frac{G\cos\alpha}{\mu} + G\sin\alpha + F_f - F_s)/n \qquad (8)$$

Set the parameters of Eq(8) ,the no gliding condition is shown in Eq(9).

$$F_m \geq 80\cos\alpha + 40\sin\alpha - 41 \qquad (9)$$

The curves between each permanent magnet adsorption force (F_m) and included angle between wall and gravity (a) is shown in Figure 4.

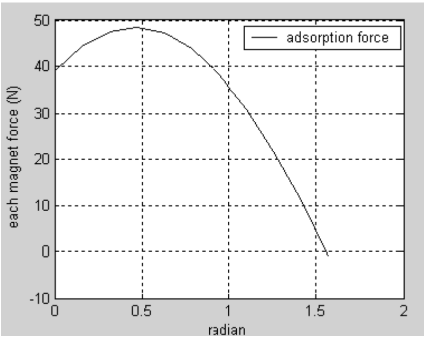

Figure 4 Gliding relation with each magnet adsorption force and angle between vessel wall and gravity

Results
According to the Figure 4, the most dangerous angle (a) is 27.5 degree, and the permanent magnet adsorption force (F_m) approximate 48N.

Tip-back analysis
As shown in Figure 3, tip-back is the robot turn back around point A, the sunction of permanent magnets must overcome the total torque arise from gravity, vacuum suction force and water jetting kick force. The moment balance is shown in Eq(10) and Eq(11) .

$$\sum M_A = (F_m - N_1)l' - \frac{(G\sin a + F_f - F_s)l + GH\cos a}{2} \qquad (10)$$

$$\sum M_A = 0 \qquad (11)$$

$$F_m = \frac{(G\sin a + F_f - F_s)l + G\ H\cos a}{2l'} + N_1 \qquad (12)$$

According to the Eq(12) ,if the robot work normally, the condition in Eq(13) is indispensable.

$$N_1 \geq 0 \qquad (13)$$

Considering the analysis of robot with water jetting kick force and vacuum suction force, the condition of attaching is shown in Eq(14):

$$F_m \geq \frac{(G\sin a + F_f - F_s)l + GH\cos a}{2l'} \qquad (14)$$

Set the parameters of Eq(14), the no tip-back condition is shown in Eq(15):

$$F_m \geq 300\cos\alpha + 240\sin\alpha - 307.5 \qquad (15)$$

The curves between each permanent magnet adsorption force (F_m) and included angle between vessel wall and gravity (a) is shown in Figure5.

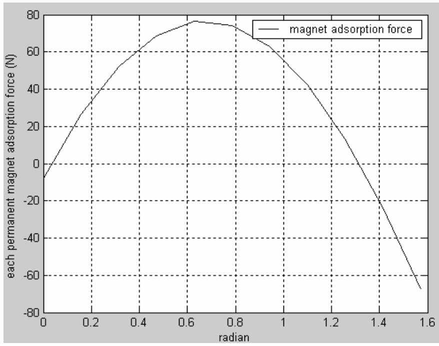

Figure 5 Tip-back relation with each magnet adsorption force and angle between vessel wall and gravity.

Results
According to the Figure 5,the most dangerous angle (a) is 34.9 degree ,and the permanent magnet adsorption force (F_m) approximate 76N.When the angle (a) is 0 to 4.1 degree and 73.4 to 90 degree, the robot will attach the vessel wall all along because of vacuum sunction.

THE DYNAMICS ANALYSIS

The means of moving is two caterpillar chains with two motors. When the robot run up, it is necessary for the output torque of the two motors to overcome the moment of resistance (M_f) which arise from magnets adsorption affinity (F_m) with holding power (N_n), and gravity (M_G). The moment balance is shown in Eq(16):

$$M_Q - M_f - M_G = 0 \qquad (16)$$

$$M_f = (F_m + \frac{F_s - F_f}{n}) \cdot h \qquad (17)$$

$$M_G = \frac{GH\cos\alpha}{2} \qquad (18)$$

By means of the analysis of dynamics, the condition of attaching is shown Eq(19):

$$M_Q \geq (F_m + \frac{F_s - F_f}{n}) \cdot h + \frac{GH\cos\alpha}{2} \quad (19)$$

THE ANALYSIS OF WALL-CLEANING

Some UHP nozzles is fitted on the robot for bringing the jetting force by high speed water to rusty scale, at the same time the tangential high speed water current brings wedge water, which can expansion the rusty scale crack, and get rid of the rust[3].

The restraint from water jetting nozzle make the speed of water jetting increased. With the jetting enter into air, turbulent flow generates jetting power loss, so the jetting speed reduces that there is no enough energy to remove rust effectively. Therefore, it is necessary to farthest utilize jetting center[4].

Given the water jetting act on the object surface and based on the momentum theorem, the total water jetting kick force is shown in Eq(20):

$$F_f = \rho \upsilon q(1 - \cos\beta) \quad (20)$$

The simulation of water jetting is shown in Figure6.

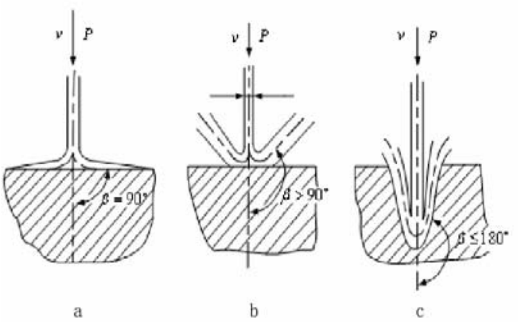

Figure6 Different reflects direction after water jetting acting on the surface of object

According to the Figure6, when the angle is β≈180 degree, the jetting is total reflection, and water jetting kick force is maximal. The distance of robot nozzles from vessel wall is also important. The good distance of the water jetting is shown in Eq (21) and the maximal water jetting kick force is shown in Eq (22):

$$l = 99.7(p/100)^{-0.88} d^{0.9} \quad (21)$$

$$F_{max} = 120(p/100)^{1.15} d^{1.75} \quad (22)$$

EXPERIMENTS

With the pressure is 250 MPa, the number of nozzles is six and the diameter of nozzles is 0.25mm, experiments is did and the data is obtained and shown in Figure 7.

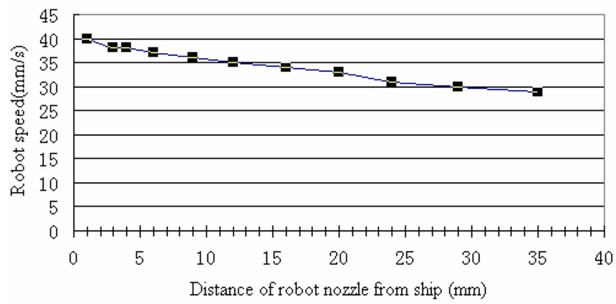

Figure 7 The relation about robot speed and nozzle distance from wall

As illustrated in Figure8, with the distance between nozzle and vessel wall increase gradually, the robot speed of advance must decrease correspondingly, otherwise, the rust will remove ineffectively.

Considering the gravity center of the attaching robot and the agility of robot control, the distance between nozzle and vessel wall was taken as 20mm and the robot speed of advance was taken as 33mm/s.

CONCLUSIONS

(1) Based on statics and dynamics analysis, three empirical equations are obtained, in these equations, the permanent magnet and motor with its redactor can be chosen well.

(2) When the distance of robot nozzles from vessel wall is 20mm and the robot speed of advance is 33mm/s, the robot is in good removing rust working condition.

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