

Study on the Applications of Extra-high Pressure Water Jet Technology

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Abstract: High-pressure Water Jet is a new technology that develops rapidly these decades. By the development of upsizing intelligentizing and customizing high-pressure water jet equipment, this technology has infiltrated into many application areas. The paper mainly discusses the mechanism of de-rusting by ultra-high pressure (short for u.h.p.) pure water as high as 200 to 250Mpa. It adopts u.h.p rotating waterjet, automatic wall-climbing and rust dregs vac sorbing and recycling. Mechanism of water-jetting de-rusting is to scour and strip the rusty scale of the converted steel surface by normal hitting power and edge angle of waterjet and twisting force of rotating. The testing proves the mechanism equation.

Key-Words: U.h.p Waterjet, De-rusting, Mechanism Testing

1 Introduction

High-pressure water jet is strong enough to use water as its medium, it produces high-speed jet bundle by pressurizing equipment and the nozzle in a particular shape, and contains energy of super thick density. High-pressure water jet together with laser beam, electron beam and plasma beam go by the general name of high energy beam process technology, among which the high-pressure water jet is the only one that cold cutting process technology. High-pressure water jet not only can cut all kind of metal, nonmetal and plastic material, but also be with simple craftwork and do no harm to physical and mechanical property of the material. Compare with all kinds of new material and composite material cold cutting performance of high-pressure water jet nowadays is without equal.

The successive emergency of new jets improve the ability of cutting detaching and breaking, which widen the application of water jet technology a lot, like pulsing jet cavitating jet and grinding jet. It can be used in cleaning, liquidating, cutting, infusion, drilling, spraying, breaking and abrading works and etc. It is clean, without pyrometric effect, energy-centralized, easy to control, efficient, low-cost, safe and easy to operate; and is now widespread applied to light industry, machine building industry, building industry, mining industry, oil interests, chemical industry, war industry, space industry, aviation, motor industry, railroad, shipbuilding industry, seafaring industry, metallurgical industry,

municipal works and medical industry, ect. It is especially suitable for working in bad and dangerous environment, and decrease the intensity of labour, improve working condition, and prevent hazardous accident effectively.

Besides this we can also use extra-high pressure technology to sterilize and keep food fresh, and do other things that favor the society.

It's a big engineering problem to remove the rust from watercraft to big tank. The steel boards will be gnawed in the sea water, and oxidized in the air. This oxydic film is called rust. We must remove the rust before painting the metal; the process is called surface per-treatment in technical terms.

After Dry Blasting and Abrasive Water Jet, the writers try their best to realize the extra high pressure water-jet by raising up the pressure to 200~250MPa, which will the power of pump assembly so as to achieve the desired derusting speed. At the end of 90s, they mainly devoted themselves in desusting and rust-proofing, they used automatic wall-climbing robot instead of manual ejection gun, and made the robot adhere to the wall by recycling rust remains in vacuum. The realization of this technology which centering on extra high pressure water-jet makes the wet de-rusting commercialized.

2 Applications of Extra-high Pressure Water Jet Technology

2.1 Extra-high Pressure Water Incision

Water incision can be used in papermaking and rubber industries, and sand water jetting can be used in stone, ceramic, space, motor, and metal-processing industry. It is mentionable that as the rapid development of motor industry, the updating of automotive type and the curtailing of production period make the water jet equipments more extrusive to the factory that produce interior ornament, i.e. motor caplet, instrument panel and ceiling. High-pressure water pipe can be wound round the arm of the robot spirally. We can use the robot's arm and wrist to make the nozzle of the water incision move lineary and curvilinearly rapidly, so as to work the interior ornament triaxially. It can do optional curvilinearly one-off incising working to any material, while other incision will be limited by the material types. Cold incision will produce no heat and hazardous substance while incising, there will be no pyrometric effect, there will be no or easy to be rework. Water incision is nowadays the most flexible incising technique for its safety, environment-protect, low cost, high speed and efficiency, convenience, flexibility and versatility.

Comparing with laser incision: Laser incision equipment costs a lot, is now mainly used to incise thin armor plate and some nonmetal material with high speed and high accuracy. But it will cause cambered scrape and pyrometric effect while incising. Additionally, it is not suitable to some material, like aluminum, copper and other nonferrous metal, especially to some thick metal plate, it may not incise at all. People now do research on high-power laser generator to resolve the problem of thick-metal-plate incision, but its equipment, maintaining and consumption will cost too much. Water incision needs low investment and cost, and is adaptable, high efficient and easy to maintain.

Comparing with plasma incision: Plasma incision produces obvious pyrometric effect, and is low efficient. Water incision belongs to cold incision, and will not cause temperature distortion; it produces high-quality cut surface, needs no rework, or, easy rework, if needed.

Comparing with wire incision: While metal machining, wire incision is high efficient, but slow-footed. Sometimes it needs additional perforation and wire feeding, further more; its incising size is

limited a lot. And water incision is high-speeded and flexible; it can punch and incise all kinds of materials.

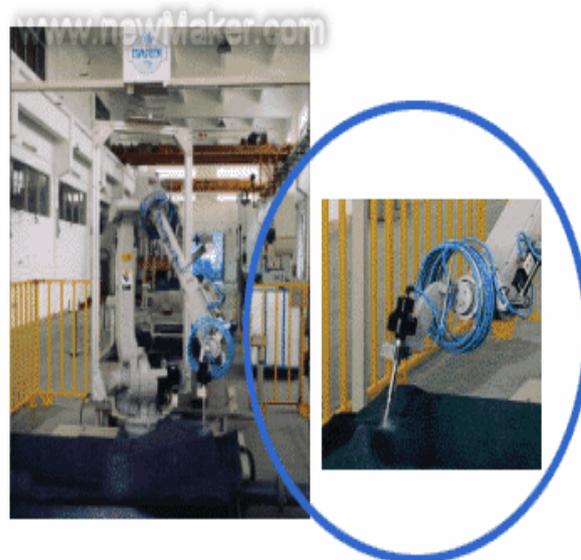


Fig.1 Incising product line of Foam, sponge and paper.

Comparing with other kinds of incision: Punching shear technology can be used to incise some metal assembly with high efficiency and speed. It needs special mould and cutting tool; while water incision is more flexible, and can incise arbitrary shaped workpiece at any time. Punching shear technology is quite difficult to apply to thick and hard material, and water incision is more ideal. Flame machining technology is often used in metal area with high incising thickness, but it produces obvious pyrometric effect, lower incision surface quality and precision. Additionally, water incision is more suitable to incise some high-melting point, alloying and composite materials.

In these secondary sectors like glass, stone and ceram, the traditional way is to use diamond tool to incise, saw and mill. It is very extensive in incision thickness, quite fast in speed. But to normal thickness plank stuff, water incision can provide high efficient and arbitrary curvilinear incision with high yield and low cost, and improves the added value a lot.

2.2 Extra-high Pressure Water Jet Cleaning Technology

Extra-high pressure water jet cleaning technology is a high technology develops in the world these years, which makes se of kinetic energy of high-speed water jet to strip the exterior bilge. It takes water as its medium and pressurizes it to 40000 PSI, i.e. 300

Maps through large-capacity supercharger driven by diesel set or electrical set. Then the water will be ejected through circumferentially-arranged gem nozzles which whirl by oil and air pressure; that will form an extra-high pressure whirling water jet of multi-beam, multi-angle and flexible intensity. The water jet does extra-high pressure cleaning work to these surface, internal bilge, deposit builder and stemming that need cleaning. The system is often driven by diesel set, and will work provided water. Thus its mechanical character is so good that is vehicle loaded and remodeled into extra-high cleaning vehicle easily.

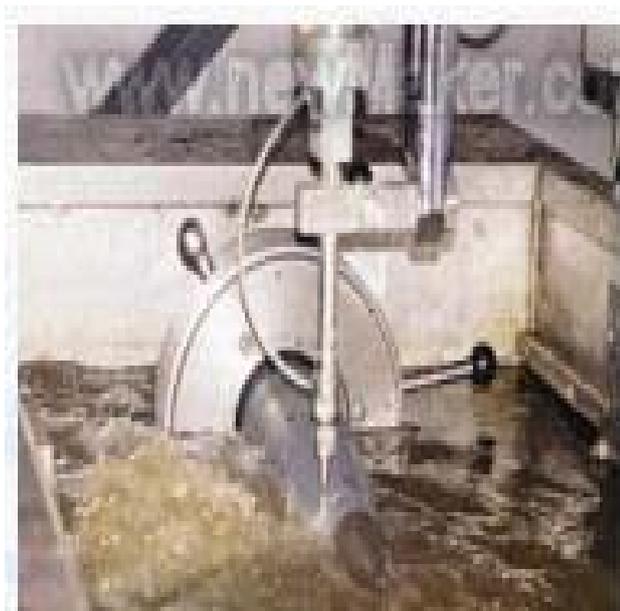


Fig.2 Incision of low-melting, flammable and explosive material

This technology is suitable for incising any deposition thoroughly, and just leaves the clean and smooth surface. It is much faster than hand cleaning, much more clean and environment-friendly; and needs no chemical medicine, solvent and etch, or any high-cost protection. Both of the cleaning and incising technologies belong to the extra-high pressure water jet technology, only the former is with higher flow rate and lower pressure.

2.2.1 Comparing with Other Cleaning Technologies

Extra-high pressure water jet cleaning belong to physical cleaning technology, compares with manual and mechanical cleaning, chemical and biological cleaning, and other cleaning technology, it has the following strong points:

- The flow and pressure of water jet are adjusted expediently, so it does no harm to the basal body.
- Extra-high water jet causes no secondary pollution; it needs no recleaning unless required.
- It is suitable for washing complex shape and structure objects, and able to work in narrow space and on other bad conditions.
- Be different to chemical and biological cleaning, it discharge no harmful substances and pollution.
- It is fast and engrained. E.g., cleansing rate is over 95% with heat exchanger, and 95% with boiler.
- It costs lowly, as much as 1/3 of that of chemical cleaning. For extra-high pressure water jet belongs to thin jet, is power frugal.
- It has no special requirements for materials, property and shape of the equipment, the only thing needed is satisfactory water jet.

2.2.2 Technology Area

The following are the main technical parameters of the large extra-high pressure water jet in the world:

- Pressure: 35~250 Mpa;
- Rate of flow: 40-180L/min;
- Drive: electric motor or diesel

The technical parameters of portable high-pressure cold-and-hot water flushing machine are as following:

- Pressure: 10-40Mpa;
- Rate of flow: 600-1500l/h;
- Drive: electric motor, diesel or petrol engine;
- Range of water temperature: 0~95°C;

Be applied with rubber tire, so as to move easily.

2.2.3 Application area

- Equipment department, mobile department, power department, development department, engineering department, tertiary-industry department and service corporation of power plant, chemical plant, chemical fertilizer plant, oil extraction plant, refinery, steelworks, coke-oven plant, oxygen installation, power plant, gasworks, brew house, pharmaceutical factory, sugarhouse, meat packing plant, frigorific, textile mill, rubber plant, printing and dyeing mill, etc.
- Logistics section, mow houses department, water-heating department, air-condition refrigeration department, maintenance department, administration department, general services department of guesthouse and restaurant, business mansion, government offices, hospital, school, municipal works, residential sub district, real estate management, etc.

3 Complete Descaling Technology By Extra High- pressure Water Jet

This technology aims at the Platium degree with Sa2.5 by the use of rotary u.h.p water jet as high as 200 to 250Mpa. Climbing task by robot, rust cleaning and proofing and recycling of rust dregs. The complete technology includes the following: extra high pressure pump assembly of 250Mpa and 160Kw, Climbing robot system and Vacuum adsorbing and slagging system. Illustration 1 is the sketch of complete descaling equipment by extra high- pressure water jet.

3.1 U.h.p Pump Assembly

U.h.p pump assembly is the main engine of these instruments. The following are the technical parameters: Pressure, $p=200\sim 250\text{Mpa}$; Rate, $Q=30\text{L/min}$; Power, $N=160\text{kW}$.

We should resolve the following problems if we use diesel engine and reducer to drive triple plunger pump: the average reciprocating speed of plunger piston should be under 0.15m/s as much as possible; reciprocating seal of the pump adopts slit seal by difficult-delivering elastic cylinder and aromatic polyamide materials so as to form a working circumstance not only with extra high pressure but also not easy to lock by frictional heating while reciprocating; in-and-out sluice valve adopts flat valve that grinds with spool and clack seat; to avoid stress concentration among the material, technics

and rchitectonics of the extra high pressure cylinder body; pump assembly is controlled by spillover valve of pneumatic-piston type.



Fig. 3 Rinsing of the shell of floating head exchanger

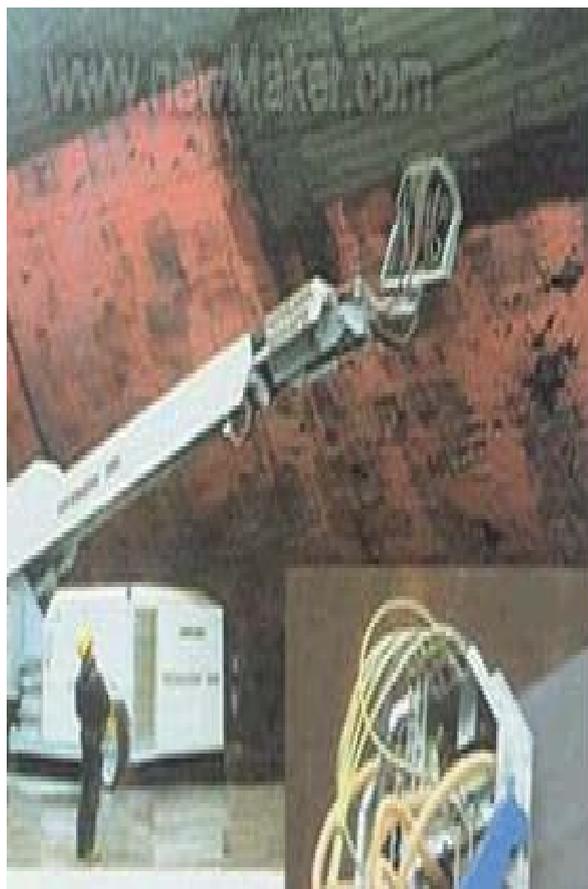


Fig.4 removing the bilge and exterioring paint

3.2 Wall-climbing Cleaning Robot

Wall-climbing robot mainly resolves the following problems: walking, wall-attaching and jetting.

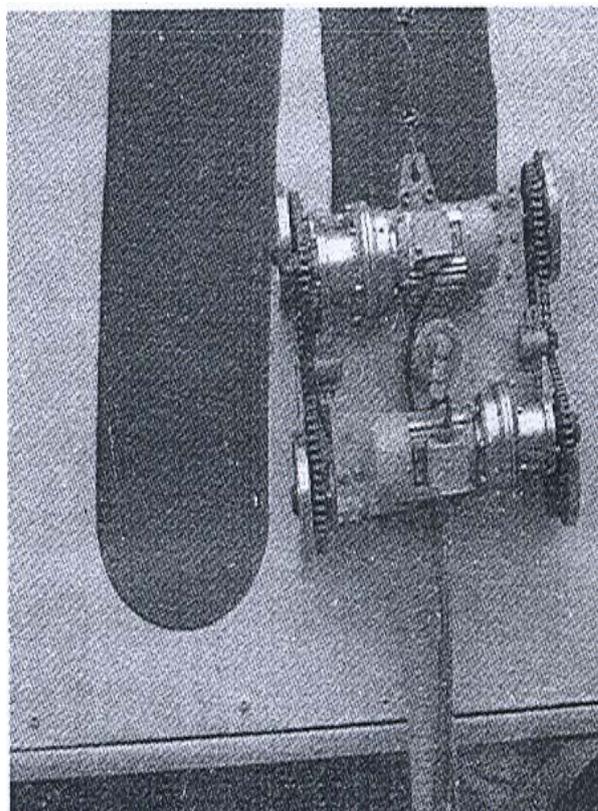


Fig.5 Photo of Wall-Climbing Robot

Walking: It adopts two-circuit motor driven mechanism and divides the four walking-wheels in to two groups (left and right group). Either is driven by a micromotor with a reducer. When the two micromotors run with the same direction and speed, the cleaning robot will do straight reciprocating motion, while either motor speeds down, the robot will change the direction and run zigzag. It requires that the torque output of the motor to be strong enough to conquer the weight of the robot, the vacsorbability and the friction.

Wall-attaching: Robot realizes wall-attaching by outside vacsorb. It requires the wall-attaching torquemoment produced by vacsorbability(vacuum degree at 0.6bar) to be stronger than joint capsized moments produced by the weight of robot itself together with impedimenta(waterpipe, windpipe, wire and the water in waterpipe, etc) and vacuum adsorbability. The wall-attaching vacuum cylinder of the robot is made of rubber material.

Jetting: As an operator the robot should be installed with a spray-head consists of a u.h.p rotating joint and four nozzles. The whirligig of the spray-head is realized by jet power of the injection stream; panel slit seal of the rotating joint makes

sure the stability and reliability of the u.h.p autogyration. Meanwhile to change the angle of the nozzle or spray pole can also lead the change of the spray-head's rotary speed.

Here are the of the robot technical parameters:

- Maximum travelling speed: 46.3mm/s (cleaning speed: 50m/h)
- Diameter of nozzle: 2*0.4, 2*0.6mm
- Width of cleaning range: 300mm
- Rotary speed of spray-head: 400 to 600rpm (adjustable)
- Maximum vacuum degree of vacuum cylinder: 0 to 0.6bar
- Weight: 55kg

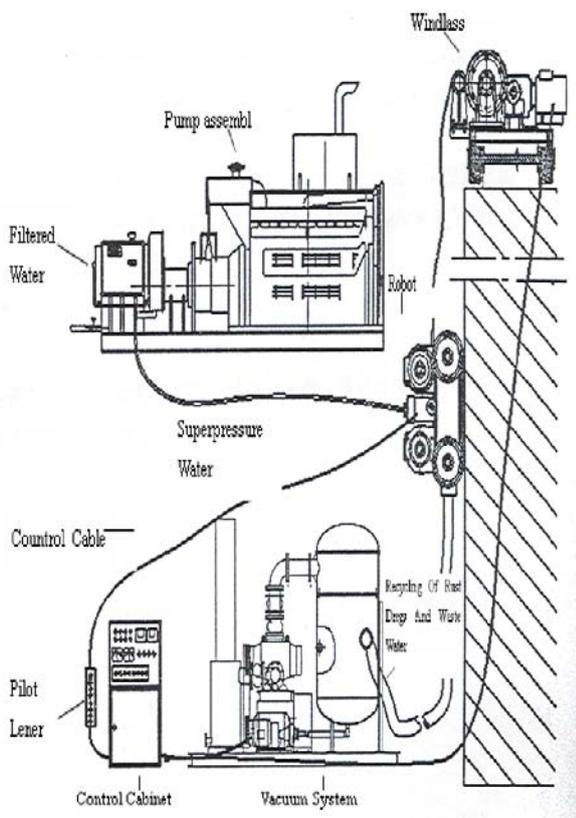


Fig.6 Complete Schema Of Wall-Climbing Rotot

3.3 Vacuum System

It has two functions: to make sure the wall-attachment of robot and to pump out the rust drags and waste water.

Obviously the level of vacuum and air suction of pump should produce enough wall-attaching moment to make sure the wall-attachment of robot, sucking rate and jetting rate should match the speed of rust cleaning. In u.h.p work condition liquid is condensable, so a well-proportioned high-temperature field will be formed in the vacuum cylinder by atomization of rotational jetting and the

change of water from ordinary pressure and temperature to u.h.p and 80 to 90°C condition. In vacuum the rust dregs and waste water will be eliminated in time and some waste water will be carbureted by evaporation in the high-temperature field, so while de-rusting by water jet, it will dry as the same time of rust removing. That is the goal that we have pursued for years: to prevent rerusting while descaling. The rust dregs and waste water will be dischargeable by filtering.

3.4 Integrated System

It's clear that it is vital to match the parameters and running speeds in the three systems. The whole de-rusting quantity (labeled by V) in unit interval is sigma function of latent parameter, that's to say if the systems interact and work harmoniously, their cooperation will be showed as whole de-rusting (quantity) and depth of de-rusting (quality).

Intelligent operation of the integrated system realizes to operate the robot remotely. The robot can climb not only on vertical and curved surfaces, but also on the superface. More over, it can remove plastocene in the bottom of large tank, if equipped with chain tread.

4 Mechanism Analysis of De-rusting by U.h.p Water Jet

4.1 Mechanism model of De-rusting

Mechanism analysis is to analyze the relationship among the parameter of work condition while waterjet and depth of cut (destroy) of material and cross sliding velocity of nozzle.

Model Schema from the Qualitative Relationship of Waterjet :

$$h = \frac{n_0 p^m m^{n_2}}{D^{n_3} U^{n_4}} \quad (1)$$

Here, n_0 n_1 n_2 n_3 and n_4 are undetermined parameter, by testing and counting, we get the results that $n_1 = 1.25$, $n_2 = 0.687$, $n_3 = 0.618$ and $n_4 = 0.866$

$$h = \frac{N_m p^{1.25} m^{0.687}}{CD^{0.618} U^{0.866}} \quad (2)$$

Here, N_m stands for particular parameter of destroyed material which is changeable factor and can be gotten by testing, as to rusty scale, $N_m = 17.3$ by normal carbon steel; and constant $C = 8800$ by metric dimension.

By knowing the width and material of the destroyed workpiece, we can easily get the expression of cross sliding speed(or de-rusting speed):

$$U = \left(\frac{N_m P^{1.25} m^{0.687}}{C q h D^{0.618}} \right)^{1.15} \quad (3)$$

In this expression q is merit factor, it's criterion of parting material as to de-rusting, and usually $q > 1.2$

h: hill-and-dale of cut (thickness of rusty scale), mm

D: diameter of nozzle, mm

P: Pressure of water jet, MPa

U: cross sliding speed, mm/s

m: flow rate of waterjet, L/min

The testing of the model has corroborated unanimousness of the two.

Following is the testing data:

h (mm)	N _m	P (MPa)	M (L/min)	C	D (mm)	U (mm/s)
0.50	17.3	200	30	8800	2*0.4	46.3
2.00					2*0.6 1.02(V.W)	10.35

4.2 Sub-atomic Model While Waterjet Attacking the Target Material

Illustration 2 is the assay plan of loading stress, stress by hitting of waterjet on this point should be expressed as following;

$$\sigma_{rr} = \frac{p}{2\pi} \left[(1-2\nu) \frac{1}{r^2} - \frac{2}{r^2(r^2+z^2)^{\frac{1}{2}}} - \frac{3r^2z}{(r^2+z^2)^{\frac{5}{2}}} \right] \quad (4)$$

$$\sigma_{zz} = - \frac{3pz^3}{2\pi(r^2+z^2)^{\frac{5}{2}}} \quad (5)$$

$$\sigma_{\theta\theta} = \frac{p}{2\pi} (1-2\nu) \left[-\frac{1}{r^2} - \frac{z}{r^2(r^2+z^2)^{\frac{1}{2}}} \right] \quad (6)$$

$$\sigma_{rz} = - \frac{3p}{2\pi} \frac{rz^2}{(r^2+z^2)^{\frac{5}{2}}} \quad (7)$$

Displacement of target material(rust scale) u (radial direction), (tangential direction) and w (long direction) are given respectively:

$$u_r = \frac{(1-2\nu)(1+\nu)p}{2\pi E_r} \left[\frac{z}{(r^2+z^2)^{\frac{1}{2}}} - 1 + \frac{r^2z}{(1-2\nu)(r^2+z^2)^{\frac{3}{2}}} \right] \quad (8)$$

$$v_\theta = 0 \quad (9)$$

$$W_c = \frac{p}{2\pi E} \left[\frac{(1+\nu)E^2}{(r^2+z^2)} - 1 + \frac{r^2z}{(1-2\nu)(r^2+z^2)^{\frac{1}{2}}} \right] \quad (10)$$

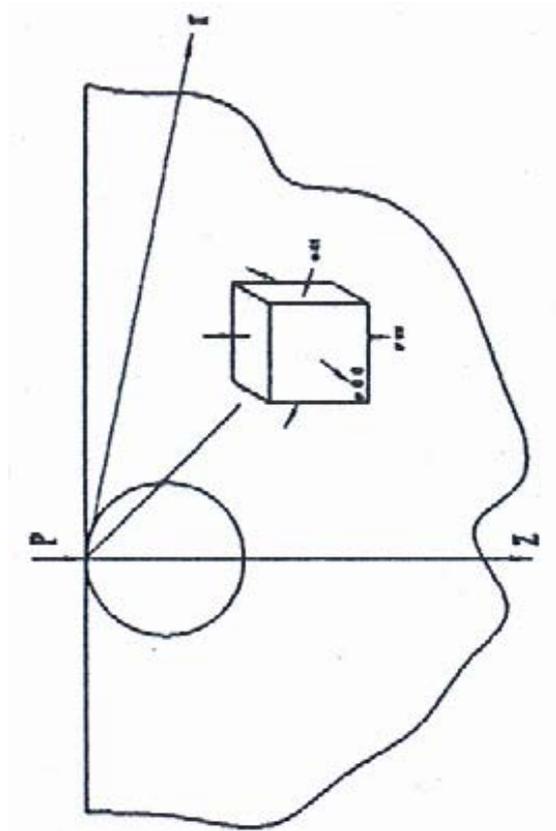


Fig.7 Point P In Circular Cylindrical Coordinates

4.3 Working Performance

The emphasis of those analyses is working performance, that is the de-rusting (removing) rate and rate of water consuming under certain waterjet working condition. Obviously,

$$R_r = T \cdot W \cdot hm \quad (11)$$

$$W_c = \frac{C_D \cdot \pi \cdot D^2 \left(2 \cdot \frac{P}{\rho_w} \right)^{\frac{1}{2}}}{2R_r} \quad (12)$$

In this formula:

R_r: rate of rust-removing, m²/min;

T: Cleaning speed, m/min;

hm :average width of rusty scale, m;

W_c: rate of water consuming in elemental area, m³/m²;

ρ_w : density of water

CD: coefficient of waterjet from nozzle, CD =0.7, comparing with C_n.

5 Mechanism Schema of De-rusting

Illustration 3 shows the microshape of rusty scale. Picture a is about the surface topography, by the dwindling pictures we find that the real problem is about roughness concentration. Picture b is about the skin effect, which divides the steel surface into fertile material, transition material layer and complete surface layer, and consists of shell effect and core effect. While de-rusting, the first thing to do is to remove the complete surface layer and round the valley bottom, then to fix the transition material layer by different level of de-rusting so as not to destroy the fertile material.

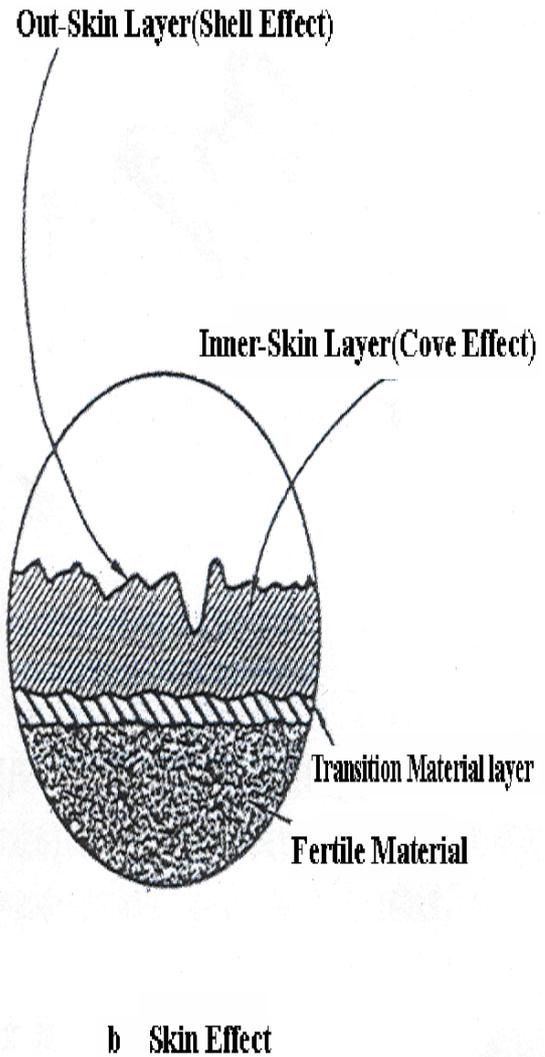
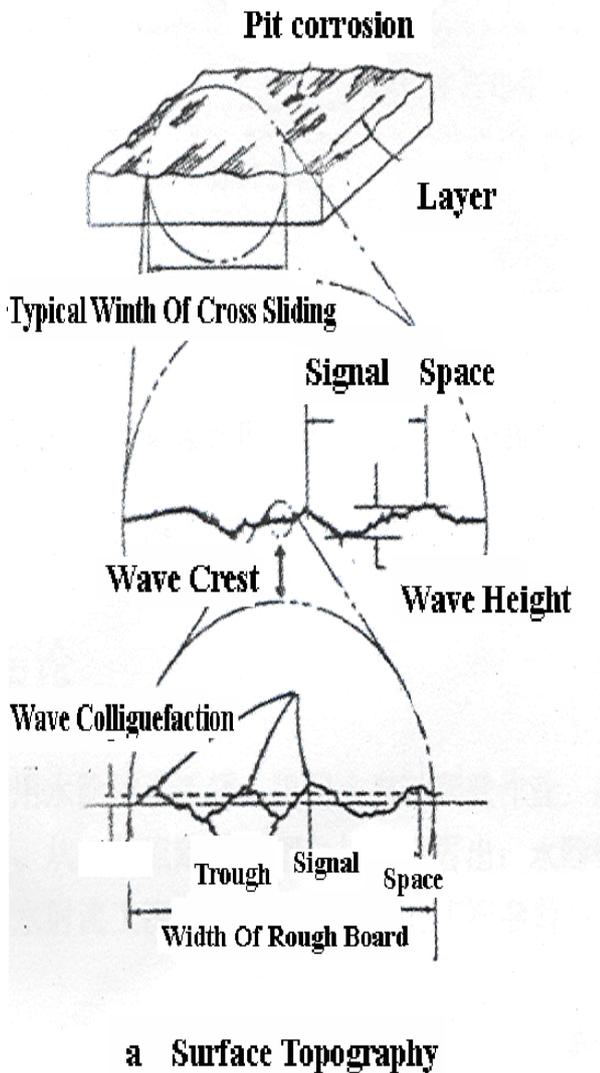


Fig.8 Topography And Effect To Rusty Scale On Steel Surface

As Illustration 4 shows, the streamling changes its direction and produces flexural moment on the effect of rotating jet current and its movement, especially to the irregular rusty surface. The high shearing load formed by rotating jet current plays an important role on the place which bears high flexural moment.

There will be rotary moment of the spray head if the nozzle is fixed at a certain angle, meanwhile, bending hitting power and shearing stripping power will be forced on the irregular surface. Test has proved that shearing stripping power demands the angle of nozzle would better be between 30° to 60°, and bending hitting power demands 60° to 90°. Integrating the two demands, installation of the nozzle should actually meets the demands of the two dimesions formed by nozzle, lance boom and rotator(as illustration 5 shows).

Particular phenomena of cracking and pitting may happen on rusty scale. This kind of cracking and pitting often immerge into the fertile material, which is called corrosive pitting. And elimination of corrosive pitting should be done after large area descaling.

Testing has proved that there will be no rerusting within 15 hours if the de-rusting quality achieves Platinum(Sa2.5) level.

6 Conclusion

Water de-rusting with no rerusting, automatic wall-climbing and u.h.p pure rotating waterjet can meet all needs of pretreatment to steel surface. It is easy to get the result form the mechanism analysis of de-rusting by waterjet that the mechanism of de-rusting by waterjet is very simple, and the real issue is to produce reliable working condition of u.h.p rotating waterjet and whole technology. The optimal parameter of waking condition are as following:
 $P=200\sim 250\text{Mpa}$, $Q=30\text{l/min}$, $N=160\text{kW}$.

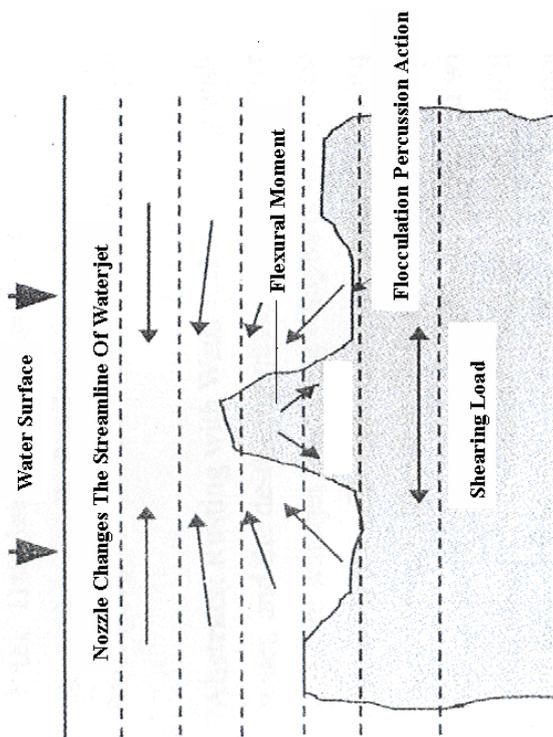


Fig.9 Force Diagram Of Irregular Surface Under Water Jetting

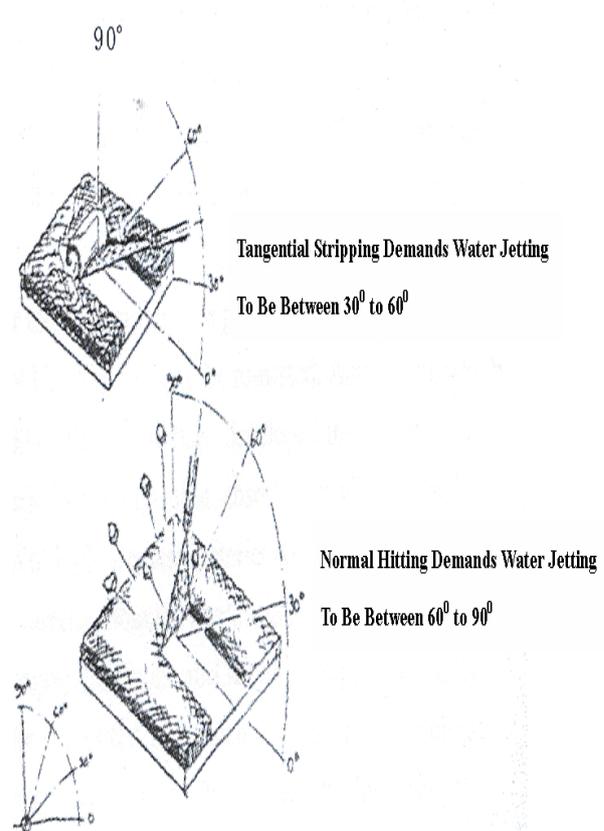


Fig.10 Mechanism Of Normal Hitting Power And Tangential Stripping

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