

Service Robot for Hull-Blasting.

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***Abstract** - Present grit blasting technology for hull cleaning is very pollutant, environmentally unaffordable, and it is progressively forbidden in the most environmental countries (mainly north of Europe). At the time being, the above methodology has been partially substituted by ultra high-pressure water blasting, however they do not show as good performance as the grit blasting systems. This paper describes a service robot for hull blasting. The technology we developed consists of the cleaning head, the robot body, the remote control unit and the teleoperation platform. This solution allows a reliable and cost effective operation regarding hull grit blasting, obtaining a high quality surface preparation (SA 2 ½ together with a dramatic reduction of waste and zero emissions to environment. A prototype of the robot has been developed and tested in IZAR shipyards. We presents the functional requirements, system concept and architecture of this robot. This work was supported by the Spanish government, the European Union (CICYT-FEDER) and IZAR CARENAS S.A.*

I. INTRODUCTION.

Besides the first hull surface preparation when vessel is built –before painting it-, main ships' maintenance care consists of periodical (every 4-5 years) removal of sea adherence and hull coating and afterwards hull re-painting. This is carried out to preserve the hull integrity, guarantying safe-sailing conditions, and to maintain a smooth hull surface, minimising fuel consumption, reducing operation costs and avoiding too atmospheric contamination. Other maintenance operations are scheduled or even delayed to be done while hull cleaning and re-painting. Present technology - see figure 1 - [3][7] [8] for hull cleaning, grit blasting, is very pollutant, environmentally unaffordable, and it is progressively being forbidden in the most environmental sensitive countries (mainly north of Europe) only remaining in southern countries (Greece, Portugal, Spain) with a clear trend to be reduced until being definitively forbidden.

At the present moment, the above methodology has been partially substituted by ultra high-pressure water blasting [4][8]. Those systems avoid the pre-water cleaning required for hull desalinisation used with grit blasting; however –as

reported by paint suppliers and ship owners -, they do not show as good performance as the grit blasting systems, since:

1. This technology does not satisfy requirements regarding steel surface preparation for optimal paint adherence, as ship owners notice it.
2. Maintenance period is extended by 30%.
3. Blasting operation cost increases by 30% together with a high amount of water to be recycled (water is a limited and expensive resource in southern countries of Europe).

These features are producing that ship owners move to shipyards where the open grit blasting is still allowed (South of Europe, Middle East, Far East, Korea and China), with loss of ship repair work in yards of the North of Europe (where open grit blasting has already been forbidden).

This paper presents a robotics system for hull grit blasting capable to obtain a high quality surface preparation together with a dramatic reduction of waste and zero emissions to environment. This technology is integrated in a full-automated and low-cost blasting system.

II. GRIT BLASTING VS WATER BLASTING.

Usual renewal periods for modern auto polishing paints are four to five years, with some intermediate hull cleaning every two years. This second operation does not include coating removal, but only sea adherence removal. Common hull cleaning systems use high-pressure fresh water hoses at pressures of 250 Kg/cm² through 750 Kg/cm². The hull water cleaning is normally carried out in order to remove salt from within the steel hull. This operation is performed because paints employed adhere better on a non-or less salted surface. One of the most universally used paint/coating removal technologies is the open grit blasting; this consists of manually operated hoses that projects grit with high speed through injection of pressurised air at 79 Kg/ cm². Grit blasting in open spaces is progressively being forbidden in the most environmental sensitive countries, to avoid atmospheric contamination caused by the dust produced as a consequence of the grit impact against the steel hull. On the other hand, grit blasting produces residues of non reusable grit detritus, combined with paints, sea moulds and barnacles

over big area (2,5 times greater than the rectangle determined by the hull area) inside the dry dock where the grit blasting is performed. Such residues may contain contaminated parts (for example, in the case where TBT paints are used to avoid fouling of the hull) and therefore the above-indicated area must be cleaned after blasting, and the residues disposed adequately on an authorised sink.



Figure 1. Grit blasting for hull cleaning.

The most recent development in abrasive blasting equipment is remote-controlled or robotic-type blasting units for vertical surfaces [1][7]. These units are designed to crawl along the surface of a ship hull, a storage tank, or a cooling tower while being operated from the ground. These units are equipped with either centrifugal wheel or compressed air blasting units, as well as, vacuum recovery, filtration/separation, and supply/waste storage systems.

Specially designed shrouds around the blasting heads "seal" the units to the surface being cleaned to prevent the dust from escaping into the atmosphere. There are different methods of accessing the surface with the blasting head unit. In each case, the remote controlled equipment for the robotic blasting unit is located on the ground. In fact, it is often packaged together and mounted on a trailer or skid for ease in transporting it around the job site or from one project to another.

One method [7] of reaching the vertical surface is to attach the robotic unit to the platform of a scissors lift or to the end of a telescopic or pneumatically controlled arm mounted to a

vehicle, such as a cherry picker, which allows the unit to transverse the blasting surface. In some cases, the arm is permanently mounted to a dry dock installation. The arm allows for horizontal and vertical movement of the unit within a given range. Another method is to suspend the unit from rigging that is attached to a girder mounted at the top of the surface to be cleaned. The robotic unit can move horizontally along the girder as well as vertically in a fixed location. Finally, magnetic force or a counterweight, aided by vacuum power, can be used to attach the blasting unit to the surface, thus allowing for relatively free movement of the unit. The surface and spent abrasive. Recyclable grit or a mixture of grit and slag can be used by these blasting units, depending on the surface to be cleaned, the contaminant to be removed, and the desired degree of cleanliness.

A surface cleanliness of SA 2, SA 2 1/2, or SA 3 can be achieved with this equipment, depending of the abrasive media used and the unit's rate of travel, dwell time, etc. Cleaning rates achieved with vertical dry blasting equipment also depend on the nature of the surface to be cleaned, the standard of cleanliness required, and the width of the blast pattern. In addition, the degree of flatness of the surface is a factor, since the blasting head must be kept against the surface to maintain dust-free operation.

Advantages of the current remote-controlled vertical blast-cleaning equipment includes dust-free cleaning, speed operation without the need for scaffolding and the resultant savings in scaffolding and labour costs. Disadvantages include 1- more up-front expense for equipment compared to traditional blasting units, 2-the possibility of cumbersome set-up (e.g., rigging a support beam from the top of the surface), and in some cases, 3-the need to scaffold the surface for painting (i.e., if it cannot be reached from a cherry-picker or permanent staging in a dry-dock). In other hand, these equipment are very heavy and their utilisation for spotting or the bow is not recommended.

At present, the above methodology has been partially substituted by ultra high pressure water blasting (UHP) [8][10][11]; it uses technology derived from those employed for hull hydro-cleaning, but attaining to pressures around 2.000 - 2.500 Kg / cm². Those systems avoid the pre-water cleaning required for hull desalination used with grit blasting; however, they do not show as good performance as the grit blasting systems. Main problems concern [4][8]:

- Surface finishing: The steel surface roughness obtained is not good enough to permit a correct adherence of the prime coating (in comparison with the one obtained by the use of grit blasting).
- Execution times: The time required to perform a degree of hull blasting is generally 1,6 times the one required to perform the same job using grit blasting.
- Waste disposal: The use of fresh water (a limited resource in southern countries of Europe) for hull cleaning and / or hull water blasting, also produces the same residues of paints, sea moulds and barnacles, and therefore a system has to be put in place to filter all such residues and avoid them go along with water. An

additional problem appears when the local legislation requests for water recycling. Then, an additional system to recycle the used water has to be installed.

GRIT BLASTING	
Grit characteristic	Dehumidified and gauged Cooper and Zinc pyrites slag
Granulometry	Between 0,5 and 2,0 mm
Working Air Pressure	7 Kg / cm ²
Surface Preparation	SA 2 ½ SA 2, SA 1 (Svek Standard Sys.)
Average Measured Consumption per m ²	SA 2 ½ 45 Kg SA 2 34 Kg
Average performance per man-day	SA 2 ½ 50 m ²
WATER BLASTING	
Projected material	Fresh water
Working pressure	Between 250 and 2.500 Kg / cm ²
Water Consumption Cleaning	250 Kg/cm ² 90 l/min 750 Kg/cm ² 40 l/min
Water Consumption Blasting 2.000 Kg / cm ²	8 l/min
Average performance per man-day Cleaning	110 m ²
Average performance per man-day Blasting	30 m ²

Table 1. Grit blasting vs water blasting.

Table 1 summarises the performances obtained using both technologies under real conditions. The data proceeds from the shipyards of IZAR and using human operators, not robotic systems.

Like the robotic dry-blasting equipment for vertical surfaces exist robotic units equipped with ultra high-pressure (UHP) water-jetting nozzles [9][10][11]. They have one or more sprays bars that hold the spray nozzles, and they feature vacuum recovery, filtration/separation, and waste storage systems. Ultra high-pressure water is supplied to the nozzles by intensifier or conventional plunger pumps, which can be powered by a diesel or an electric motor. The pumps and separation systems are located on the ground where they may be mounted on a skid or a trailer for easy transport. As with vertical dry-blasting machines, the UHP waterjetting units have shrouds that surround the blast nozzle heads and seal them to the surface being cleaned to prevent the escape of debris or used water.

Depending on the manufacturer, these units may be made as free-crawling machines, or they may be made to be attached to the end of a telescopic arm mounted to a self-propelled vehicle or to dry-dock installation. In either case, the units are operated by remote control from the ground and held against the surface by means of magnetic force or vacuum.

The free-crawling machines have either twin tracks or wheels at each corner. A winch system is used to position the unit on the surface from the top. It also serves as a safety device to support the unit should it accidentally become separated from the surface.

Since waterjetting without an abrasive does not produce desired surface profile, use of this technology is restricted to maintenance work. Standards of steel preparation with UHP waterjetting are available from SG in Germany, several marines paint companies in Europe, and from SSPC: The Society for Protective Coatings and NACE International in the United States.

Advantages of remote-controlled UHP [3][8] waterjetting units for vertical surfaces are the same as those for the dry-blasting units for vertical surfaces: dust-free cleaning, speed of operation without the need for scaffolding; saving in scaffolding and labour costs. Disadvantages include 1-ship-owners [1][4] prefer grit blasting instead water blasting (by reason of the obtained superficial quality) , 2-more up-front expense for equipment compared to traditional waterjetting units and, in some cases, 3-the need to scaffold the surface anyway for painting if it cannot be reached from a cherry-picker or from permanent staging in a dry-dock.

III. SELECTION OF BLASTING TECHNOLOGY

Based on the study of the state of the art in hull cleaning, a robotized system based on grit blasting has been adopted. To reach such selection, exhaustive tests have been done in order to select which of the different abrasives in the market is the best.

Three different abrasives were chosen based on parameters as hull surface cleaning reached with every abrasive, recycle capability, and respectful with the environment and working conditions: Ti-Grit[®], Webusiv[®] and Alodur-DSO[®].

In order to check the effectiveness of the abrasives, real tests were done in a ferry beached on IZAR shipyard. After a water cleaning to eliminate superficial dust, different parts of the hull was blasted with a distinct abrasive – see figure 2. The painting thickness was measured in every area, varying between 371 and 606 µm. Two tests were done for every abrasive with 100 Kg of material in every test, recording the time to waste totally the abrasive getting a hull surface cleaning of SA 2 ½. The blasting unit used was an EDHER twister 130, with a working pressure of 7 bar.

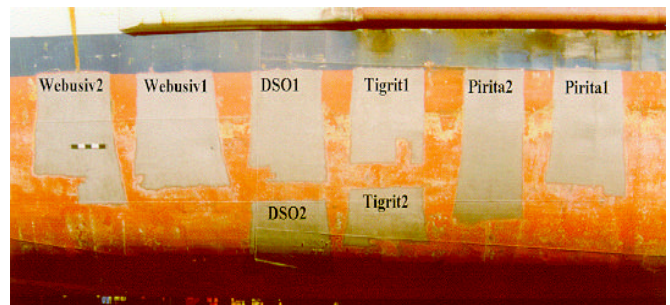


Figure 2. – Different blasting on the hull.

In this tests, several parameters were measured, including a granular study, efficiency in time of blasting, using cost, and very important: reusability. The obtained results offer the following conclusions:

- All these abrasives are efficient in the hull surface cleaning reaching SA 2 1/4 quality.
- The consume and cost of Ti-Grit is higher than the others
- Ti-Grit is the most recyclable abrasive, it can be reused 200 times, Webusiv and Alodur-DSO 5 times and Cu scum only twice.

Therefore, Ti-Grit is the optimum abrasive for this work. Although the cost of the material is higher, its superior reusability makes this cost the least. This will be optimum keeping in mind that a recycling system must be used.

IV. REQUIREMENTS FOR A ROBOTIC SOLUTION TO HULL BLASTING.

In this section, the objetive is to summarize some of the high-level requirements for a robotic system for the purpose of hull cleaning/blasting applied to ships maintenance:

- ✓ The robot shall be adaptable to the shapes of very different ships, from an oil tanker to a war frigate.
- ✓ The blasting material shall be able to achieve a hull surface cleanliness of SA2 1/2. Furthermore, in order to reduce the amount of residues, it should be reusable several times.
- ✓ The cleaning head shall be able to eliminate residues due to dust emission. A recycle system will be coupled to the cleaning head. It will treat all the non-recyclable products as a result of the cleaning process. Basically it will separate the reusable grit from the residues.
- ✓ The robotic system will be able to support the cleaning head and carry it along the ship surface that has to be cleaned. In order to delimit the problem a few assumptions are made:
 - ✓ The working area is defined from 1 meter to 6 meters altitude all along the ship.
 - ✓ The cleaning of such area will be carried out in a totally automated manner covering areas of 2.5×2.5 meters.
 - ✓ The movements from one area to another will need very few maneuvers.
- ✓ The cleaning head will have the necessary degrees of freedom to carry on the blasting process in the most efficient manner. Which means that the angle of incidence of the blast on the surface of the ship will be approximately of 45 degrees in the sense of advance of the cleaning.
- ✓ The capacity of load of the robot will be adequately measured in order to support the weight of the cleaning tool, the hoses and other auxiliary elements that could be manipulated. It will be less than 150 Kg.

- ✓ When designing the robot, the necessary protections have to be placed so that the grit blasting and the dust will not damage different elements of the robot. In the same way, an adequate protection to confine the projected material, dust and the residuals generated during the operation must be placed.
- ✓ For the span and dimension of the robot, the conditions of the environment of work must be strongly kept in mind: possible presence of strong winds, possible presence of inflammable and explosive substances, irregularities in the surface of the land, existence of obstacles, etc. For this, the combined robot-cleaning head has to be the most compact and slight possible, in order to be the most easily maneuverable.
- ✓ The combined robot-cleaning head will be teleoperated by a computer following the commands that the operator introduce in the interface, so that as many areas of the ship as it is possible could be covered, simplifying the design of the system. A teleoperated platform will provide the final user all the necessary services in order to supervise and control the deaning operation. This platform will communicate with a control unit of the robot, which controls the movements of the effectors that compose the cleaning robot-head, as well as it registers the operation mode and state of operation in that moment. Therefore, the system eliminates the hard working conditions of the workers in the present manual operation, being necessary only controlling operators.

V. ROBOT STRUCTURE.

The robot we developed - see figure 3 - consists of :

- (1) The robot body (including the cleaning head). The robot's structure has been built integrating commercial elements. The objective that has been pursued is obtaining a robot of very low cost. We have used a commercial platform to obtain the movement in the axis Z. The approach movement of the cleaning head to the hull is carried out by means of two commercial lineal guides. These support a hydraulic cylinder that is the one in charge of displacing the blasting hose.
- (2) The motion control system for manoeuvring the robot along the hull surfaces. This is based on an industrial PC running RT LINUX and GLADE.
- (3) The teleoperation platform fed with CAD data from hull under operation and the process parameters, able to control and coordinate up to ten robots in order to reach optimum quality minimising resources and the time consumed.
- (4) The waste dealing and recycling systems to eliminate the residues resulting from the hull blasting, in order to provide adequate treatment of them, to permit the reuse of the grit material, and to package and dispose adequately the other wastes.

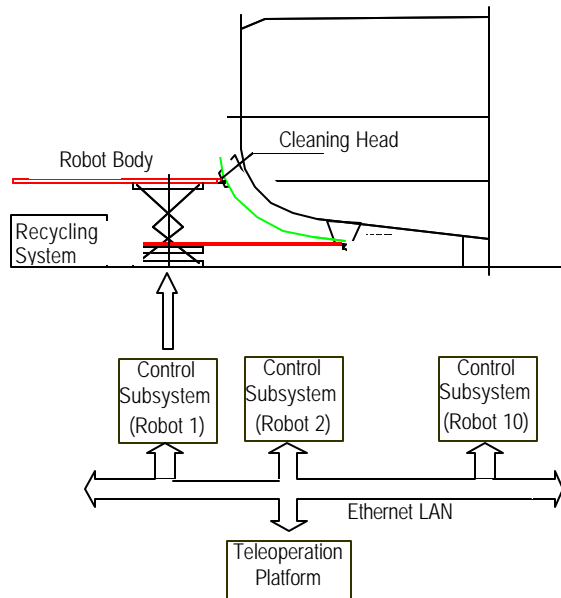


Fig. 3. Structure of the hull blasting robot.

VI. THE ROBOT BODY.

The robot body is a assembly of the following parts:

- ✓ **Elevation platform.** This part -see figure 4 consists of an hydraulic elevation platform, whose minimum height is 800mm and it has a career of elevation of 2500 mm. Therefore, it is able to clean the fringe of the ship between 800 mm. and 3300 mm high. For the rest of the surface to be cleaned, a supplement of 2500 mm. high is added, in such a way that one could sweep the fringe of the hull between 3300 mm. and 5800 mm. The capacity of load is enough to carry the arm, the head of cleaning, and in anyway, the supplement.
- ✓ **Arm for positioning the head.** Its purpose is to move away or approach the cleaning head to the surface of the ship. It is built starting from two mobile guided rails, each one supported for a pair of skates. In their other end the rails support a pneumatic cylinder without offspring that carries the head of cleaning. The useful career of the arm will be of 4000 mm from the end of the elevator table. The arm allows approaching the cleaning head to the surface of the ship, depending of the height to which the elevator table is.
- ✓ **Cleaning head.** The cleaning head consists of a pan & tilt head that guides the hose of blasting in such a way that the angle of incidence of the blast on the ship surface is approximately 45°, in the sense of advance of the same. All the set is closed by a sealing mechanism, the conjunction use of an air spring and adjusting springs allows to achieve a flexible contact between the seal and the hull.

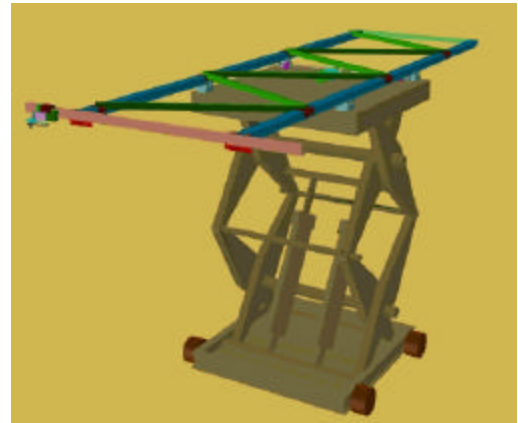


Fig. 4. Robot body.

VII. CONTROL SYSTEM ARCHITECTURE.

The control system architecture is shown in figure 3. It is basically composed by two computer subsystems. Each control subsystem is in charge of driving the corresponded robot operation. The teleoperation platform shows the state of the robots to a human operator, which can drive its operation remotely. These subsystems are connected by a dedicated ethernet LAN.

The control subsystem is in charge of directly handling the robot. It should control the movement of the motors and the start and finish of the blasting operation. It gets from sensors the current status of the motors in the robot and outputs the required actuation signals. It provides a number of commands for letting the teleoperation subsystem to drive the robot.

The teleoperation platform performs the following operations:

- ✓ Display graphically the current state of the robot. For this purpose, it request this information periodically to the control subsystem.
- ✓ Accepts commands from the user for guiding the robot operation.

Two computers are used because of the different nature of the operations to be performed. In addition, the functional requirements advise for using different platforms: one with powerful graphical capabilities, for showing the robot and the operational environment with enough detail, and the other with appropriate hardware for interacting with the robot. The robot control subsystem runs on an industrial PC, while teleoperation subsystem is based on a O2 Silicon Graphics workstation, with powerful graphics capabilities.

The design and implementation of both subsystems have been made following a reference architecture for teleoperation robots developed by us in 1997 [9][14][15]. We also have applied this architecture with successful in several robotics applications inside the nuclear industry [10-12].

VIII. CONCLUSIONS.

In this paper we have presented a low-cost solution for hull cleaning that allows to obtain high quality surface preparation. The system is respectful with the environment and it has been successful validated in IZAR shipyards.

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