Galician Maritime Technologies // nº7 // 2021

GMT by ACLUNAGA

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ENGINEERING MAGAZINE by ACLUNAGA

ACLUNAGA
ASOCIACIÓN CLUSTER DEL NAVAL GALLEGO

GALICIAN MARITIME TECHNOLOGIES // nº7 // 2021

It was so simple!!!!...applying an electric current to water to obtain hydrogen.

From there, it can get as complicated as desired. Waste-water can be used, discontinuous electricity can be used to obtain an easily accumulated energy vector, the heat generated can be used to economise in other applications, hydrogen can be added to any other product and create other fuels or hydrogenate metals, of course the reverse operation can be done in a fuel cell and electricity can be obtained again...and many more possibilities.

When the major oil-exporting countries have set their sights on hydrogen, there is not much more to add.

Hydrogen is here to stay. In fact, its obtaining goes somewhat faster than its direct industrial uses. And new types of electrolysers are sure to emerge that will improve the efficiency of existing ones.

In these days of spring 2021, as we begin to receive, with some anxiety, good news about the situation of the global pandemic caused by COVID-19, we must all be focused on the economic recovery of the country.

Referring to the industrial sector in the region of Ferrolterra, in a situation that was already bad and which has been aggravated by the latest news about Siemens-Gamesa and the As Pontes thermal power plant among others, it is more necessary than ever a decisive boost from all the actors: industry, technology centres, the university and the administration.

And that impulse seems to be well underway in our area with the initiative of the Xunta de Galicia about a state pact for the recovery and industrial transformation of the region.

At the state level we are close to having the draft POEM (Ordinance Plan for Maritime Spaces) for the coming years. It will surely be the starting point for the birth of floating wind power in Spain, in which we are in a privileged area for its exploitation and unique in terms of personnel, facilities and experience for its design, manufacture and assembly.

The Port Authority of Ferrol-San Cibrao is ready to help this industrial recovery and, of course, the expectations could not be better. With an outer port in full expansion and close to having communication by train, as well as a container terminal "Deep Sea" with great growth expectations.

We have a number of concessionaires who are delivering record numbers. I´m referring to Reganosa and Forestal del Atlántico. But not satisfied with these figures, both companies have their sights set on decarbonisation in the same way that Navantia Fene does, being at the forefront of the global offshore wind market.

In recent months, several companies have set up, or are in the process of setting up, in the outer port. Endesa continues its plans to seek out new traffic. Wood and wind energy components continue to come out continuously and Alcoa, despite the chronic problem of energy prices, continues to devour 60,000 tons of bauxite every 5 days continuously, acting as the only producer in Spain of such a strategic material as is primary aluminium.

Let us add to all this the creation of a wind power hub in Ferrolterra, the forthcoming opening of a steel thermal treatment centre, the construction of the F110 frigates (currently taking up all the engineering capacity in the area), the imminent distribution of Next-Generation funds among companies with large projects in the area and some other steps being taken to improve communications infrastructure

I think we should be reasonably optimistic as well as seriously concerned about the responsibility that comes on top of us

Let's not miss this opportunity!!!

INDALECIO SEIJO

President of Ferrol-San Cibrao´s Port Authority

A SHIELDING GAS THAT PROTECTS BEYOND THE WELD POOL

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INTRODUCTION:

Fusion welding applies a very localised focus of energy to fuse the components to be joined. The weld pool must be protected from atmospheric contamination through a flux or a gas based protection.

As a supplier to the welding industry, it is our aim to "bring the spotlight on the welder" and provide them with the right means to make their work easier. By supplying high quality shielding gases, we help the welder to achieve good quality welds more easily. This will, of course, have an impact on productivity and profitability, which must also be taken into account.

SHIELDING GAS PROPERTIES

The primary function of the shielding gas is to protect the weld pool or to avoid contact of the surrounding atmosphere or air with the molten weld metal. This is required as most metals, when heated to their melting point in air, have a strong tendency to form oxides and, to a lesser extent, nitrides. These reactions can cause weld deffects such as oxide, porosity and deterioration of the weld metal.

In addition to providing a protective atmosphere, the shielding gas and its flow rate also have a pronounced effect on the following:

- Characteristics of the arc.
- Mode of transfer.
- Welding metal, mechanical and metallurgical properties.
- Weld penetration and weld bead profile (weld geometry).
- Productivity factors (welding speed, post-welding cleaning and arc time)
- Environmental conditions or emissions of fumes and gases.

The choice of the shielding gas varies depending on:

- Type of material (mild steel, stainless steel, aluminium...).
- Welding process and consumables (MIG/MAG or TIG, FCW, MCW, SW).
- Metal transfer mode (short arc/pulsed/spray arc).
- Material thickness and surface conditions.

These are the most commonly used components in a shielding gas:

Inert gases:

- Argon (Ar).
- Helium (He).

Active gases:

- Oxygen (O_2).
- Carbon dioxide (CO_2).
- Hydrogen (H_2).
- Nitrogen (N_2).

The most commonly used mixtures and gases are the following:

- Argon (TIG y MIG).
- Helium (TIG y MIG).
- CO_2 (MAG welding or CO_2).
- Argon + CO_2 (MAG).

- Argon + O_2 (MAG).
- Argon + CO_2 + O_2 (MAG).
- Argon + He (TIG y MIG).
- Argon + He + CO_2 (MAG).
- Argon + H_2 (TIG).
- Argon + CO_2 + H_2 (MAG).

ADDITION OF OXYGEN AND CARBON DIOXIDE TO ARGON AND HELIUM

Pure argon gives excellent results in MIG welding of non-ferrous metals or TIG welding of any material. However, pure argon protection in MIG welding of ferrous alloys causes a very erratic arc with insufficient penetration and arc pressure, undercuts, as well as a negative tendency to penetratation. The addition of 1 to 5% of oxygen, or 3 to 25% of carbon dioxide to argon, or argon/helium mixtures, provides an important improvement in arc stability and reduces the tendency to form undercuts and the risk of insufficient penetration.

Carbon dioxide additions to argon can also improve the configuration of the weld bead by producing a more defined pear-shaped profile, as illustrated in the figure below:

The addition of oxygen to the gas improves the weld pool flowability fluidity, penetration and arc stability. Oxygen also decreases the transitional current at which spray transfer is achieved. The tendency to produce undercuts is reduced, although oxidation of the weld metal may be increased by higher oxygen content.

Pure argon/CO_2 mixtures (up to 25%) are used in carbon and low alloy steels, and to a certain extent (max. 3% CO_2) in stainless steels. The addition of carbon dioxide can produce adverse effects such as an increase in the transition current to spray transfer, more spatter and lower arc stability.

Argon-carbon dioxide mixtures are mainly used in dip transfer applications, but they can also be used in spray transfer and with pulsed current.

The mixture of argon with 5% carbon dioxide has been widely used for pulsed current welding with carbon steel wires. For pulsed current welding with stainless steel wires, mixtures of argon, helium and carbon dioxide are preferable.

ARGON-HELIUM-CARBON DIOXIDE SHIELDING GAS MIXTURES

Mixtures of argon, helium and carbon dioxide, commonly called “tri-mix”, are used with pulsed current

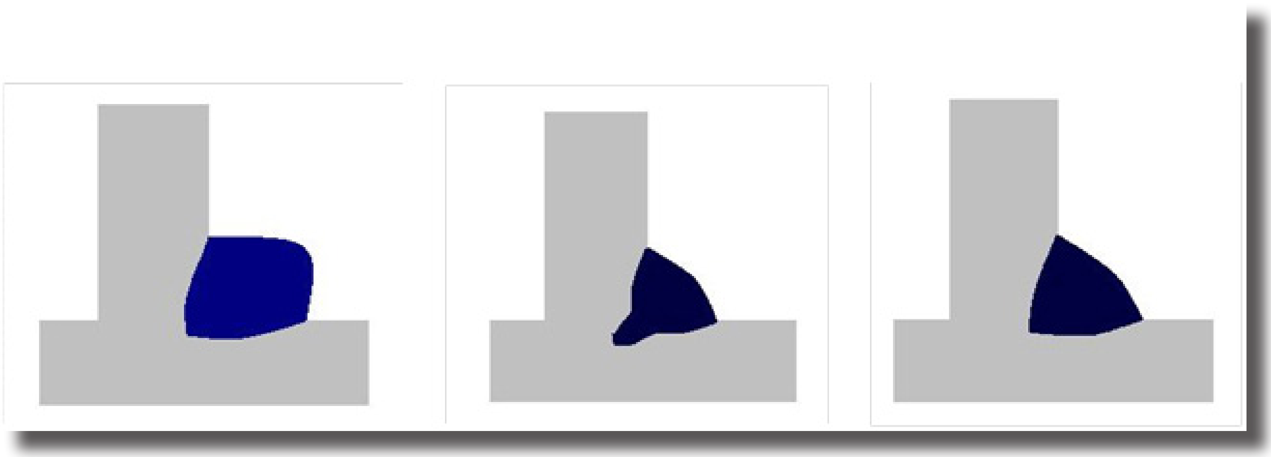


Figure: effect of CO_2, argon and Ar/CO_2 mixtures on the penetration profile for MAG welding.

welding and short-circuit of carbon steel, low alloy and stainless steels. When quality and productivity are required, these blends can also be perfectly applied for high production welding with high deposition MAG welding of stainless and low alloy steels.

HELIUM IN SHIELDING GASES

Helium added to shielding gases for MAG welding of carbon and low alloy steels tends to reduce silicate and slag formation in the weld and creates a more convenient weld profile. Helium has higher thermal conductivity than argon and produces an arc plasma with a more uniform arc energy distribution. On the other hand, the argon arc plasma has a high-energy inner core and a lower-energy outer zone. This difference significantly affects the weld bead profile. A helium-shielded welding arc produces a broad parabolic weld bead. By having higher thermal conductivity, helium will produce a higher penetration profile, better wetting characteristics and higher welding speeds can be obtained, offering flatter welds with a better profile. Therefore, the economic factor of welding is an important issue when using helium gases to weld mild steel, stainless steel or aluminum and their alloys, as well as materials with high thermal conductivity such as copper or their alloys.

For aluminium welding in particular, the comparison of a shielding gas such as argon with a typical argon/helium mixture (70/30) results in significant improvements.

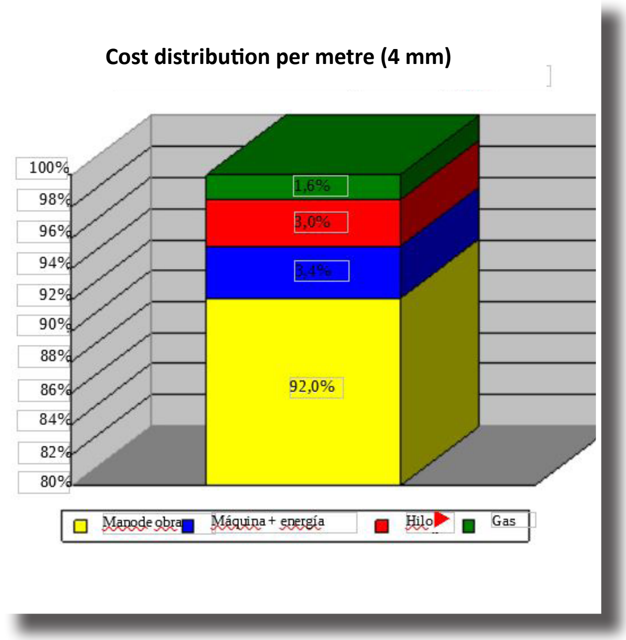
HYDROGEN

Hydrogen (H_2) can be added to shielding gases for TIG welding of austenitic stainless steels to reduce oxide formation by creating a reducing atmosphere resulting in a brighter and cleaner weld. The addition also means more heat in the arc and a narrower arc, which improves penetration and welding speed. It also provides a smoother transition between the weld bead and the base metal. It is only suitable for austenitic stainless steels.

PRODUCTIVITY AND PROFITABILITY: THE ECONOMICS OF WELDING

The profitability of welding can be increased by reducing costs in many areas. Costs are the result of many factors, as illustrated in the next diagram.

Shielding gas costs are only a small part of the total welding cost. Manpower and capital costs together can easily account for up to 90% of the total welding cost. This offers great possibilities to reduce welding costs.



There is a clear trend and focus towards increased productivity in the welding sector. But productivity is driven by many other factors than "welding speed" and "higher deposition rate". Of course, these factors are important, but the following ones also are key on welding costs:

- The arc duration is affected by post-welding operations such as:
  - grinding of overly convex welds.
  - defect repairs (cracks, porosities,..).
  - removing of projections.
  - post weld cleaning.
- Joint volume.
- Process efficiency or loss of material by projections.
- Degree of preparedness.
- Welder's comfort

Cost calculations show that increasing the arc time by 1% significantly affects welding costs.

In addition, all this can vary depending on the welding method, but when considering MIG/MAG and TIG welding separately, the choice of shielding gas is important for all the factors you can see below.

The right choice of shielding gas can result in the following:

- Flatter welds (addition of O_2 and He).
- Less projections on the workpiece (addition of O_2).
- Increased process efficiency (O_2-He).
- Less post-treatment cleaning up (H_2-He).
- Faster welding (O_2-He-H_2).
- Superior, consistent quality and more favourable penetration (He-O_2-H_2).
- Less porosity.

This shows that a shielding gas not only protects the molten pool, but also makes your and your welder's life easier.

CONCLUSION

The correct choice of the shielding gas for the welding operation can lead to significant reductions in overall cost.

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V80R4.0. THE SENER APPROACH TO THE INDUSTRY 4.0.

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FORAN is a CAD/CAM/CIM tool used in the design and construction of vessels and marine structures, developed by SENER. FORAN started 50 years, it has always been at the front end of the technology and is currently licensed at more than 150 shipyards and design offices in 40 countries.

It is the only software of its kind on the market, as it encompasses every aspect of design in a fully integrated manner and because it is used at every stage of the design and production of a vessel.

Since the launching of the release V80R3.0 by end of July 2019, SENER has continued improving FORAN System in all its disciplines.

The development effort has resulted in a great number of improvements in the entire system, and some of them includes new technologies as the Artificial Intelligence. This paper introduces a few of the new capabilities available in the release V80R4.0, launched May 2021.

As regards the digital revolution capabilities, SENER has developed the FORAN Assistant, a new Artificial Intelligence based tool for online assistance: https://foran-assistant-prod.eu-de.mybluemix.net/.

NEW VISUALIZATION ENGINE

Another area for improvements has been the implementation in all graphic modules of a new and modern visualization engine with several new functionalities. Some of them are following explained:

- Dynamic highlight (see figure 1). When moving the mouse over the scene, selectable objects are automatically highlighted.

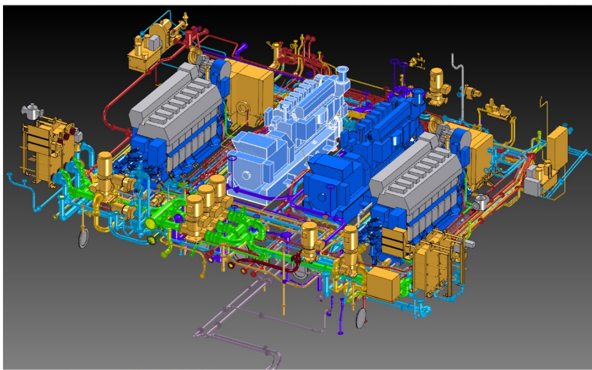

Figure 1: Dynamic highlight example. When moving the mouse over the scene, selectable objects are automatically highlighted.

- New selective mode. Selective mode highlights the intended objects, making transparent those elements that have less interest but are useful for a reason.
- New navigation system. User can navigate through the scene without changing mode. This mode is integrated with the mouse wheel in a very intuitive mode.
- Compatibility with graphic cards and 3D graphic libraries.
- New user preferences file editor. Visualization preferences can be edited in an extensive, easy and comprehensive dialog. Values are stored in preferences files.

• Transparent mode for real limits (see figure 2). Real limits display is replaced by the new transparent mode giving a more realistic visualization.

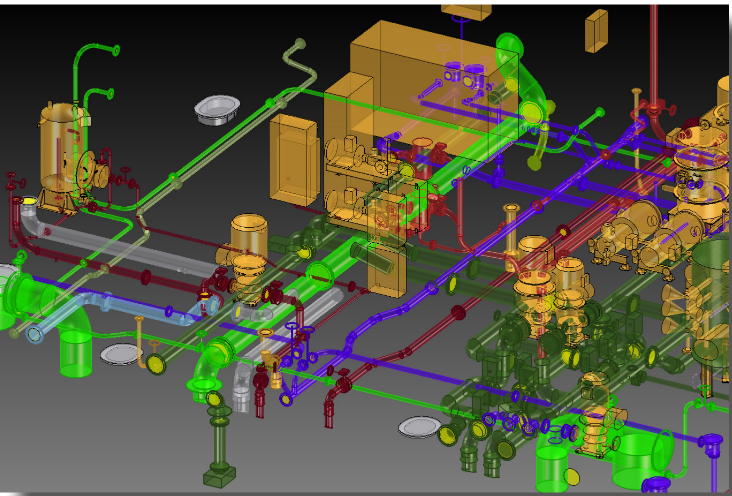

Figure 2: Transparent mode for real limits. Real limits display replaced by new transparent mode giving a more realistic visualization.

• Raytracing display mode (see figure 3). It is possible to activate ray-tracing mode for detecting shadows and dark places.

INITIAL DESIGN SUBSYSTEM

FORAN Initial Design comprises the Hull Forms, General Arrangement and Naval Architecture calculations, all integrated with the other design disciplines in FORAN, which ensures data integrity, fast propagation of changes, multi-user access and the reuse of information in later stages.

In the V80R4.0 a new set of improvements have been developed, being the following just a few of them:

• Domestic Chinese Stability criteria for River and Seagoing Fishing Vessels.

• Automatic generation of damages.

• Additional requisites for Australian Stability Criterion.

• SOLAS Stability criteria updated to 2020.

• Possibility of using friction coefficient in dynamic launching and parallel force calculations in launching and floating calculations.

• Dredging ships stability criteria (DR-68 and Spanish Maritime Directorate).

• Stability criteria MSC.415(97) for ships engaged in anchor handling operations, towing and escort operations and lifting operations.

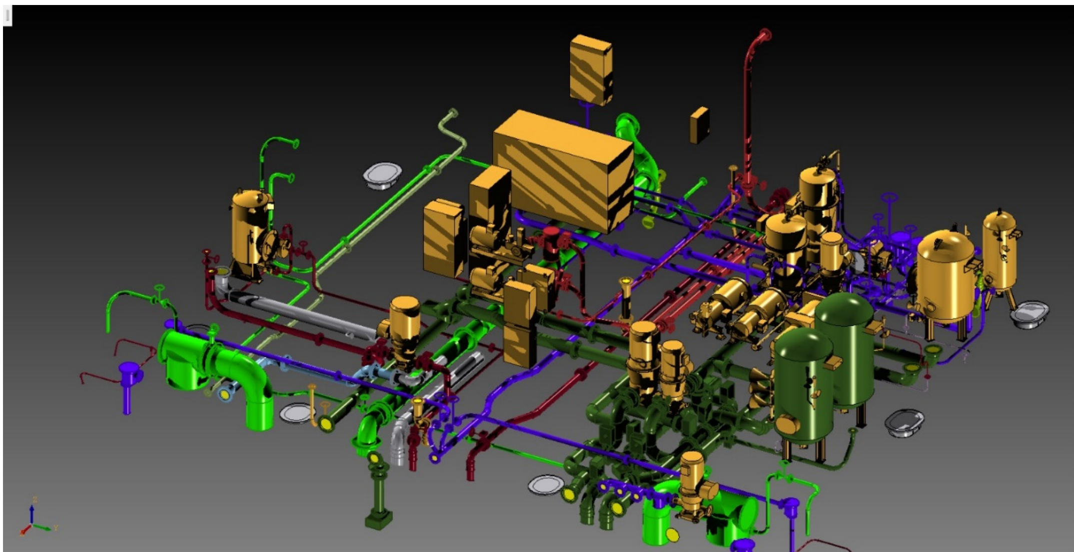

Figure 3: Raytracing display mode. It is possible to activate ray-tracing mode for detecting shadows and dark places.

STRUCTURE SUBSYSTEM

FORAN Hull Structure provides a complete solution for definition of the 3D model of the structure, and for the automatic generation of all information required for manufacturing.

The V80R4.0 has brought new features. Below, some of them:

• Improved user experience of applicability management in series projects.

• 3D jig model drawing.

• Unlimited number of drawings based on a set of different templates.

• New context to preview cutting sequences: CNC viewer.

• New labelling concept for display and hide side in marking labelling pattern.

• Improvements in welding visualization.

• New architecture for postprocessors to generate cutting sequences.

MACHINERY AND OUTFITTING SUBSYSTEM

FORAN Machinery and Outfitting continues the design process by incorporating all aspects related to equipment, piping, HVAC ducting and auxiliary structures into the same project-centric database used for the ship structure.

A single tool manages the equipment, piping lines, HVAC ducts, auxiliary structures and supports. Finally, all information for fabrication and assembly is generated automatically, including fab sketches, isometrics, drawings and reports.

In the list below, some new functionalities:

• Advisory of the impact in series projects due to modifications of some elements:

• Impact assessment report due to design changes.

• New context for pipe isometric edition and drawings.

• Management of variable-radius bended pipe pieces and instruments with several connection points.

The possibility to add dimensions in FDESIGN spool drawings has been implemented. A new area in drawings template, see figure 4, permits to configure the dimensions needed in that area of automatic drawing.

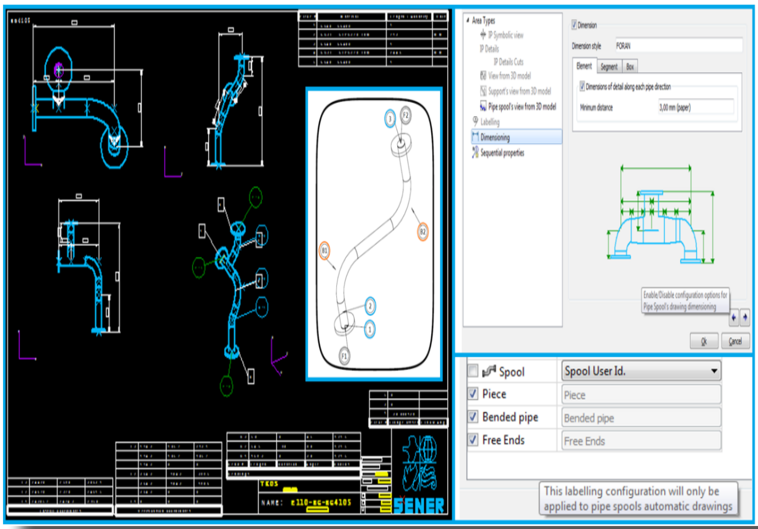

Figure 4: New area in drawings template allows to configure dimensions needed in that area of automatic drawing.

Part lists can now display bending information, installation coordinates and verification of local coordinates. New options for labelling spools drawings have been added to label.

ELECTRICAL SUBSYSTEM

FORAN provides advanced functions to manage all the relevant aspects in design and production of electrical systems. In particular, it includes facilities to create electrical diagrams, to model electrical equipment, to create 2D or 3D equipment and cableway layouts, to calculate cable sizes, to route cables, to define cable terminations, to manage instrumentation and control signals, and to generate different types of reports and drawings.

Many developments have been implemented in V80R4.0. Some of them are listed below:

• New restrictions in design operations to take into account the production maturity of the penetration.

• Interactive comparison of routes of different cables.

- Ability to highlight the route of a cable in the scene without the need of reading the nodal network.
- Verification of routing efficiency.
- Ability to list the cables routed in overfilled and overweighed segments.
- Calculation of accumulated voltage drop.

FCABLE, the FORAN module for definition of the electrical items, provides additional options and functionality in the cable tray modelling tasks, improving the user experience with easy-to-use and new user-friendly interfaces.

Some new capabilities:

- Cable tray fitting library with a new GUI using a tree view with fittings grouped in types.
- Additional options in the generation of cable trays from the nodal network.
- Functionality to visualize the 3D model of cables as a design review task as shown in figure 5.

Designers will benefit from a better and more intuitive graphic user interface in case of the cable tray-fitting library and the insertion of fittings in the 3D model. Besides, they will benefit from new modelling options that will enhance the object creation possibilities as well as their productivity.

CAD & PLM INTEGRATION

FORAN-PLM advanced integration is a solution that offers efficient sharing of information, processes, systems and databases during the design, production and operation of ships.

Some relevant improvements related with V80R4.0 are:

- FORAN-PLM FWSI plugin allows publishing to certain Windchill contexts: Repository, Library and to ProjectLink© ones.
- FORAN-PLM Teamcenter Integration will use Standard Teamcenter external application integration API, to communicate FORAN items to Teamcenter in a direct way without making use of any middleware software.
- FWSI: Interfacing multiple FORAN instances with Windchill.
- PLM web viewer in FORAN modules: including drag and drop to the 3D scene.

With FORAN V80R4.0 SENER maintains its position as a leading provider of integrated solutions for shipbuilding and the offshore industry, continually reinventing and providing customers with solutions to fulfil their needs.

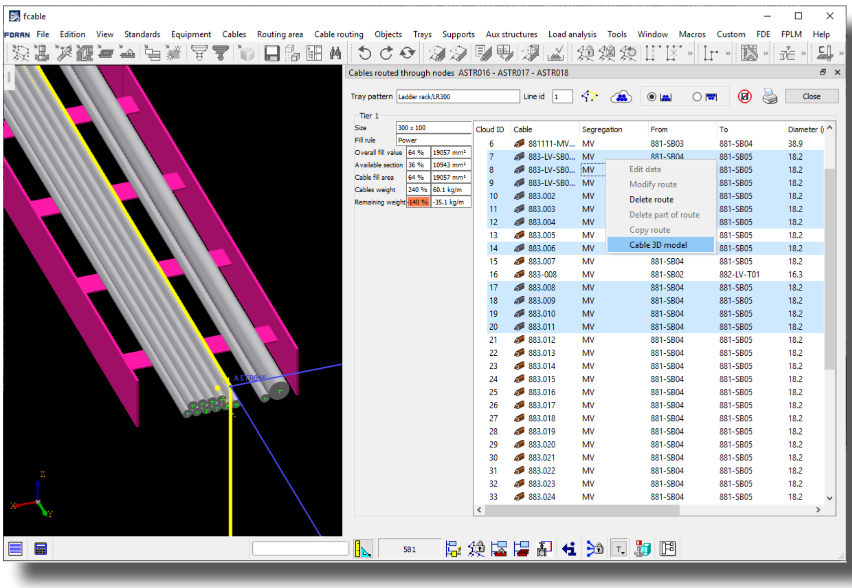

Figure 5: Functionality to visualize 3D model of cables on design review task. 3D model of cables routed in a tray segment.

NEW DEVELOPMENTS IN FRICTION STIR WELDING FOR MARINE APPLICATIONS

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INTRODUCTION

Friction stir welding (FSW) is a solid-state welding process invented by TWI in 1991 and subsequently widely used for the fabrication of structures requiring high strength, lightweight, fatigue resistant joints. The process was originally developed for joining aluminium, as this is considered a difficult material to weld, and was subsequently developed for other hard to weld metals such as magnesium and copper. FSW was quickly adopted as a fabrication technique for spacecraft, trains, shipping and automotive components, as well as electronics assemblies and consumer goods, all applications where aluminium joints needed to be made that were strong, tough, fatigue resistant and lightweight. Once the good mechanical properties of FSW joints were recognised, along with the benefits of the potentially low cost and automated means of creating them, users began to request that the process be developed for steel too.

The development of tools sufficiently strong to stir steel, and to be chemically inert to the steel itself at the high temperatures required to soften it, meant that introducing FSW to steel was a challenging undertaking. However, small scale laboratory testing showed that the quality of friction stir welds in steel could be exceptionally good and thus the quest for industrially useful FSW tools for joing steel worthwhile. Such tools are now being introduced to the market and work underway to identify and exploit the many benefits of the process. An area where FSW in steel is likely to see early use is in shipbuilding and ship repair, two areas in which TWI and ACLUNAGA are actively engaged to develop the technology as part of the RESURGAM project.

THE FSW PROCESS

Conventional fusion welding processes used for the fabrication and repair of marine structures are essentially a casting technique. The two components to be joined are brought together and energy applied, typically in the form of an electric arc or laser beam, to cause the metal at the region of the joint to melt and coalesce. As the energy source is removed this molten weld pool freezes and the previously separate components are now a single piece.

In contrast, FSW is fundamentally a technique in which the components to be joined are forged together and never molten – akin to the way in which blacksmiths heat up steel and hammer it together! To make a simple butt joint using FSW, the two plates to be joined are placed side by side and the rotating tool is lowered and brought into contact with them at the joint line - as shown in Figure 1. The rotating tool generates frictional heating and this softens, but does not melt, the metal. As the metal becomes soft and plastic, the tool is driven into it until it is fully embedded to the tool shoulder, and then traversed along the joint line. The tool continues to heat and soften the metal immediately ahead of it, and the rotary action of the tool sweeps metal around it and across the joint line, uniting the two pieces of metal as one. At the end of the weld, the tool is extracted.

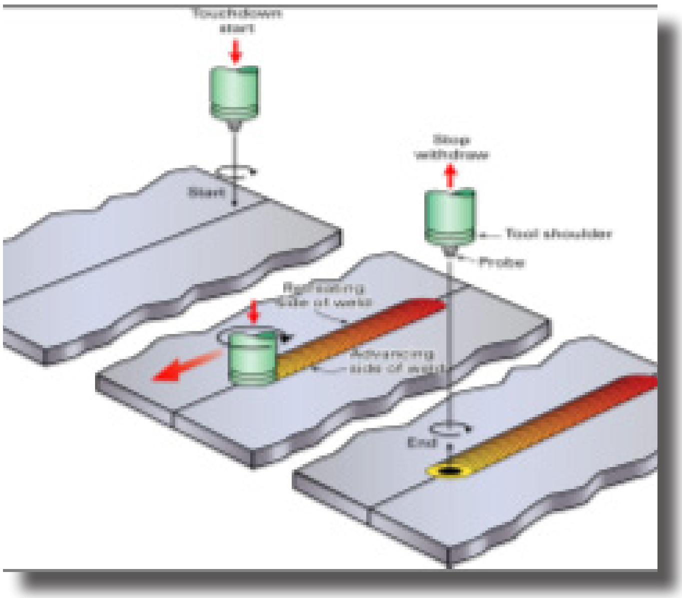


Figure 1. The general principle of friction stir welding.

The benefits of FSW arise primarily from:

- The elimination of melting in the joining process;
- The generation of a forged rather than cast weld microstructure;
- The elimination of human variability and skill from the welding process.

Considering these in more detail, the elimination of melting brings about a significant reduction in structural distortion, and enhanced health and safety benefits as there are no molten metal or fume hazards. Additionally, the process is far less energy intensive. The absence of a liquid metal weld pool also frees the process from gravitational effects and constraints: welds can be performed vertically (3G) and even overhead (4G) just as easily as a flat, horizontal weld. A further benefit is that FSW can also be performed under water, and has even been demonstrated to be effective when performed in oil. [1]

The mechanical, forging nature of FSW produces a fine grained, wrought microstructure rather than the more typical cast microstructure of fusion welding. Figure 2 shows a typical metallographic section through a friction stir weld in 6mm thick DH36 steel.

The weld shows full penetration and no significant undercutting, with no visible internal defects such as voids, shrinkage cracking or segregation. The Heat Affected Zone (HAZ) is small and the weld has a fine grained, equi-axed microstructure similar to the parent plate. As no filler metal is required for a FSW, the alloy composition remains unchanged and the costs of purchasing, storing and administering filler metals is eliminated from the welding process.

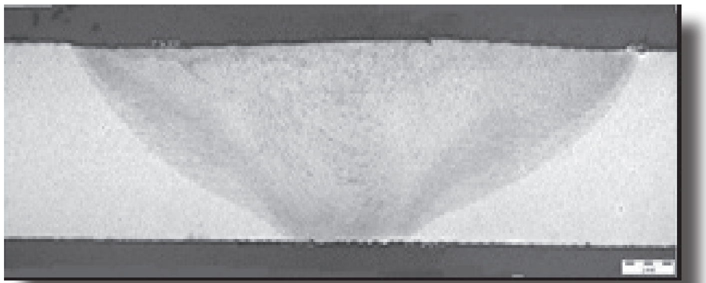


Figure 2. A metallographic section through a single pass FSW in 6mm thick DH36 steel.

Friction stir welding is a mechanised process, suitable for automation or robotisation. In its simplest form, it can be undertaken using a milling machine. The process is thus not dependent upon the skill of individual welders and so reduces process variability, allows for 24 hour operation, can be performed in hazardous environments and permits the use of in process statistical control and automated NDT / QA techniques.

The physical, forging nature of FSW places some constraints on the weld geometries that can be achieved as the two faying surfaces are required to be brought into close contact and filler metal is not available to make up any significant gaps. That said, a wide range of joint geometries has been achieved in light metals with typical examples shown in Figure 3.

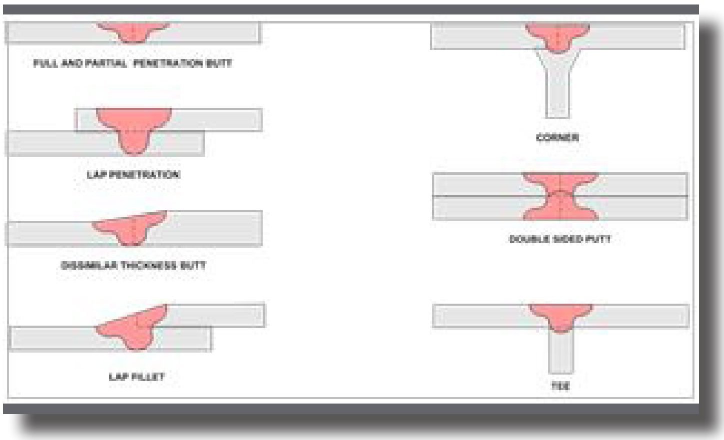


Figure 3. Joint geometries most easily achieved in FSW.

A variation of the FSW process, Stationary Shoulder FSW, has been developed and used in aluminium to allow corner and fillet welds to be produced. An example of a radiused corner fillet weld made by this technique is shown in Figure 4. Here two 8mm thick plates of AA6082 have been joined using opposing passes of a FSW tool which simultaneously joined the plates and forged the radius into the plasticised metal before it cooled.

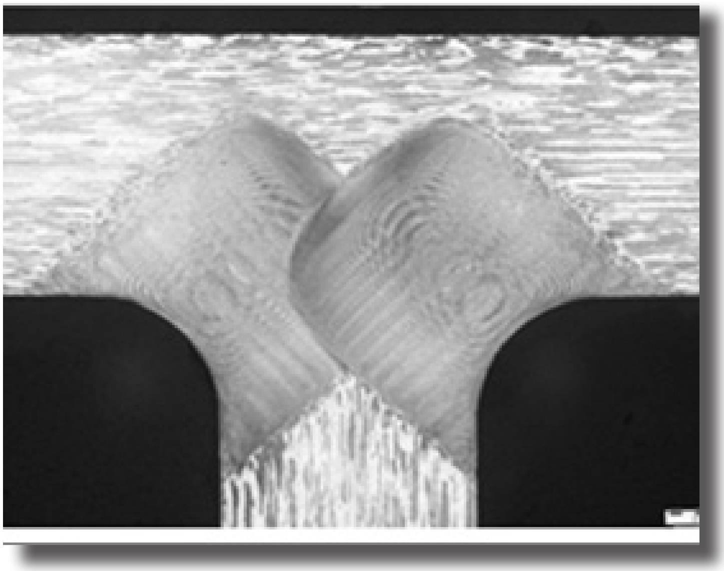


Figure 4. Metallographic section through a radiused corner fillet weld made by two FSW passes in 8mm thick AA6082.

The stationary shoulder FSW technique also permits joints to be made between dissimilar thicknesses of metal, as shown in Figure 5.

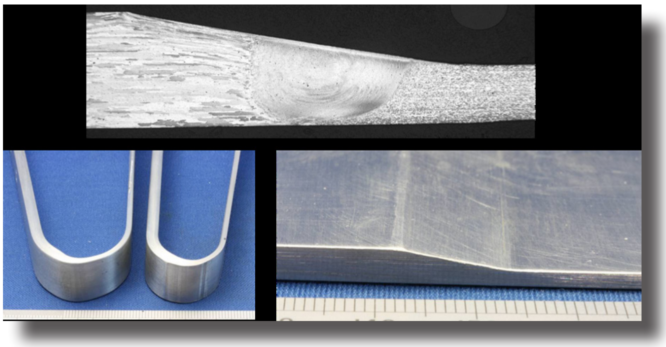


Figure 5 Example of a joint made between 4mm and 2 mm thick AA6082 sheet. The macrograph (upper) shows the weld to be defect free and the root and face bend test samples (lower left) attest to its mechanical integrity. The smooth transition between the two different thicknesses of material is shown lower right.

MARINE USE OF FSW- ALUMINIUM

FSW has been a major enabler in the development of high speed, aluminium hulled vessels, particularly fast ferries and naval patrol craft. The welds have proven to be strong and stiff, with excellent fatigue and corrosion resistance. Figure 6 shows a number of naval craft which utilise FSW in their construction.

Figure 6. The USN LCS1 and LCS2 classes, as well as the catamaran HSSV, all utilise aluminium FSW.

Civilian vessels too utilise FSW, often for the modular build of aluminium decks and superstructure components on a steel hull to provide strong, stiff but lightweight upperworks.

TECHNOLOGY TRANSFER TO STEEL

As part of the RESURGAM project, Element Six in the UK, has developed FSW tools for steel. Element Six's latest FSW tools for welding 6mm thick steel have been tested at TWI and shown to consistent from batch to batch, and capable of producing defect free welds in carbon steel under several different testing conditions. These test conditions were:

Regimen 1: Multiple 2m welds

- Multiple tool plunges into cold, hard steel;
- Tool operating several minutes at elevated temperatures;
- Typical of pipeline welding, repair welds, assembly work.

Regimen 2: Multiple 5m welds

- Fewer tool plunges into cold, hard steel;
- Tool operating typically 20 minutes at elevated temperature;
- Typical of modular construction, pressure vessels.

Regimen 3: Fewer, but longer 20m welds

- Two or three tool plunges into cold, hard steel;
- Tool operating at elevated temperature for an hour or more;
- Typical of panel production for ships.

The welds were made at a welding speed of 300mm/min in S355J2+N steel. Under all service conditions, the tools were capable of producing consistent, defect free welds. All tools tested reached an accumulated weld length of 60m, with no failures experienced during the trials. Testing is still ongoing to determine the ultimate longevity of the tools.

WELD PROPERTIES

STRENGTH

The fine grained microstructure seen in friction stir welds generally provides them with tensile strength properties closer to the parent metal than is typically the case with conventional fusion welding. With steel, this benefit is further enhanced by the fact that welding takes place in the transformation temperature range and careful selection of the welding parameters can exert a useful degree of control over the phase transformations that take place during the welding process. It is possible, for example to make welds optimised for strength or for toughness, or a combination of both, depending upon the service requirement. It is generally the case that friction stir welds in steel are found to be stronger than the parent metal in which they were made. Where friction stir welds are made between dissimilar grades of steel, for example a carbon steel and a stainless steel, the failure tends to occur in the weaker of the two parent metals and away from the weld zone.

A number of samples were taken from a single pass butt weld made in 6mm thick S355 steel with E6 tools that had accumulated more than 60m of welding and subjected to mechanical testing. These samples passed a root and face bend test, an indication that the samples had no significant defects and had a good degree of ductility in the weld zone. The cross weld tensile test specimens failed in a ductile manner in the parent metal some distance from the weld and HAZ.

The mean ultimate tensile strength of the tested samples was 562 MPa. No parent metal was tested but EN 10025-3 for S355 steel in the fine grained, rolled condition specifies a minimum UTS requirement of 520 MPa for steel less than 40mm in thickness. As the welded samples failed in the parent metal it can only be stated that the weld strength was at least equal to 562 MPa and exceeded the minimum parent metal requirement.

TOUGHNESS

The fine, multiphase microstructures generated by steel FSW give rise to welds that can also be tougher than the parent metal. Samples were taken from a FSW weld in 6mm thick S355 steel produced by a tool that had made over 60m of accumulated weld and subjected to Charpy impact testing. The Charpy impact testing was performed at -20oC and in accordance with BS EN ISO 148-1:2016. The samples were removed from mid weld thickness and notched in the welding direction through the thickness on the weld metal centreline.

Impact strengths of 49, 57 and 61 Joules KV were recorded for the three test pieces, with the mean being 56J. This is considerably in excess of the minimum specified parent metal value for S355 at-20oC, which is 27 J KV.

FATIGUE

The complex, mixed microstructure that can be generated in friction stir welds appears to be capable of providing excellent fatigue performance. Work to study this effect is ongoing but it appears that the welds are remarkably resistant to crack propagation, even in the presence of sharp edged cracks. Figure 7 shows a metallographic section through a test piece extracted from a friction stir welded, 6mm thick plate of DH36 steel. Two deliberate defects were incorporated into the weld: a lack of root penetration and a lack of sidewall fusion at the weld cap. When subjected to both simple tensile testing, and fatigue testing, the samples failed in the parent metal and not in the weld.

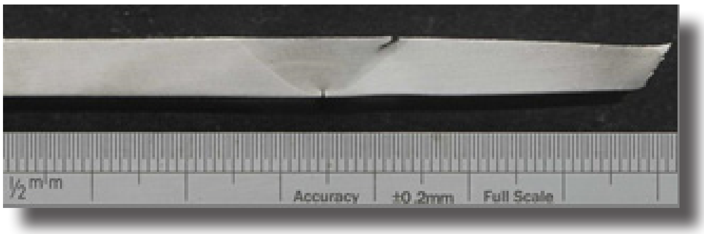


Figure 7. A metallographic section through a deliberately defective FSW in 6mm thick DH36 steel. The failure site is in the parent metal to the right hand side of the sample.

DISTORTION

A major benefit of the FSW process is that it produces very little distortion. As the metal being welded does not melt, and thus does not pass through a solid to liquid to solid phase change with its associated volumetric change (up to 4% in the case of some alloys), the distortion induced in the welded fabrication is significantly less than seen with conventional arc or laser welding techniques. The heat input to the weld zone in FSW is far more localised, and generally more rapidly dissipated, and the work pieces rigidly clamped, thus further reducing the potential for distortion.

Figure 8a and 8b show the distortion measured in identical test coupons manufactured by Submerged Arc Welding (a) and FSW (b). The SAW test piece, made in 6mm thick DH36 steel using state of the art equipment and experienced welders, had a maximum distortion of 110mm along its length. The first test piece manufactured by FSW exhibited a maximum distortion of 15mm, which was subsequently reduced to just over 2mm on a second attempt with revised welding parameters.

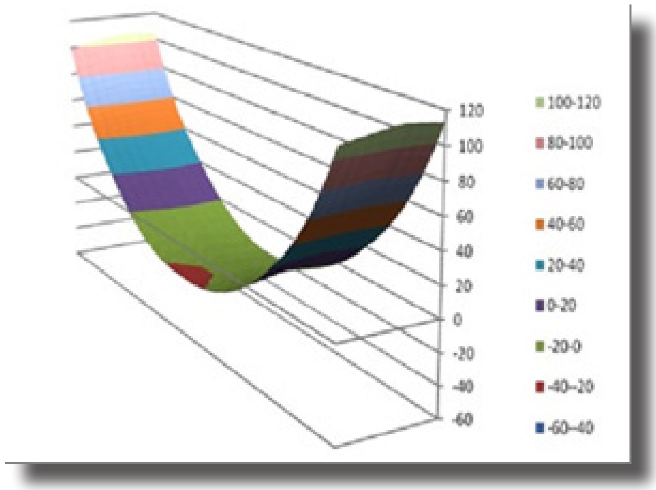
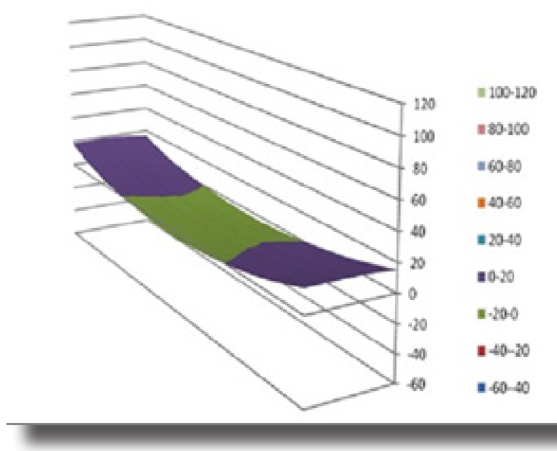


Figure 8a (above) showing the distortion measured in a SAW and 8b (below) showing the distortion in a FSW, both in 6mm thick DH36 steel. (Data courtesy of BAE Surface Fleet)



DISSIMILAR WELDS

As FSW is a solid state, i.e. no melting, welding process it is far less influenced by the alloy content of the steels being welded. It is therefore possible to weld different grades of steel together more easily than with other techniques, including carbon to Duplex stainless steels, and to weld steel grades that are found challenging to weld by other processes.

Figure 9 shows a dissimilar metal weld made between S355 carbon steel and S32205 Duplex stainless steel. From the micrograph it can be seen that no alloying has taken place between the two different steel grades, the joint is made purely by mechanical mixing. No alloying elements have been lost from either of the two grades in the weld zone, nor has elemental segregation occurred in this region. The Duplex stainless steel retained the phase balance of the original parent metal, albeit with a much finer grain size in the weld zone.

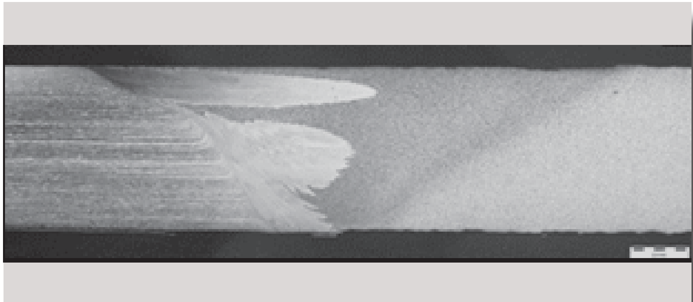


Figure 9. Metallographic section through a weld made between 8mm thick S355 carbon steel and S32205 Duplex stainless steel.

Interest has been shown by the shipbuilding industry in the potential of the FSW process to weld metals with very dissimilar plasticisation temperatures, for example joining aluminium to steel. Though this is difficult, with aluminium for example having a melting point considerably below the softening point of steel, aluminium to steel welds have been achieved at TWI. Samples taken from the fabricated plate for tensile testing failed in the parent aluminium rather than the weld, indicating that the weld strength was at least as good as that of the weaker of the two parent plates. Further work would need to be done to investigate the long term properties, particularly fatigue and corrosion of such dissimilar metal joints before it was adopted for industrial use.

INTEGRALLY STIFFENED PANELS

Stiffened panels, such as are often used for the modular construction of decks and bulkheads, are traditionally made by arc welding stiffening ribs to flat steel plates by means of a fillet weld run along either side of the stiffener.

An alternative means of manufacturing such a panel would be to weld it from rolled 'T' channel sections, forming the stiffeners, with these being spaced between flat plates as shown in Figure 10 below. This technique would replace each pair of fillet welds with a single friction stir butt weld. This would reduce welding time, simplify NDT, create a fully forged panel and reduce distortion.

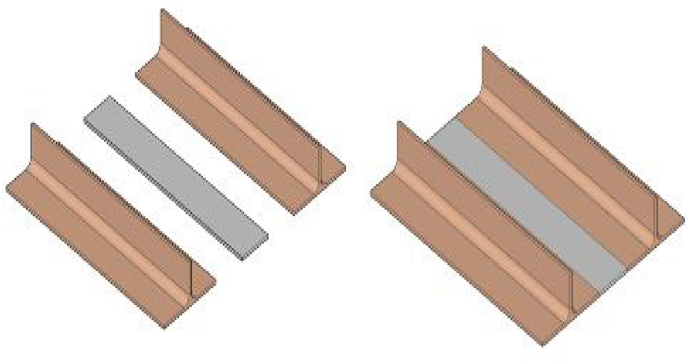
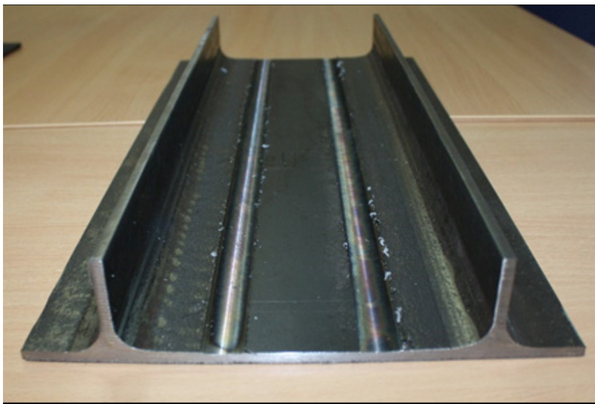


Figure 10 (above) Schematic of rolled channels and spacing plates. (Below) Example of a fully forged ISP.



PROJECT RESURGAM

The RESURGAM (Robotic Survey, Repair & Agile Manufacture) project [2], in which ACLUNAGA is a member, will combine the development of FSW technology for steel with the introduction of digital manufacturing techniques for both the initial modular fabrication of ships across multiple sites and the in water repair of damaged ships or marine structures.

The FSW element of the project will look at developing a suite of FSW tools able to weld multiple grades of steel from 2 to 12mm in thickness, in air and under water. These tool developments will be accompanied by the development of a modular FSW system that can be retrofitted to existing CNC milling and machining centres and a robotic system that can be deployed underwater to make in situ repairs [3]

These fabrication and repair capabilities, backed by the secure, digital Industry 4.0 infrastructure and techniques already in widespread use in the automotive and aerospace industries, will facilitate the rapid, coordinated but distributed modular manufacture of ships and watercraft throughout Europe.

Practically, this will allow ships damaged anywhere in the world the option of being temporarily repaired at sea without the need to travel to the nearest dry dock. This will allow ship owners to choose the most suitable yards to conduct their final repairs rather than the nearest, and the repairs may be undertaken by yards with no dry dock of their own, thus significantly increasing the number of yards able to undertake such work.

CONCLUSIONS

FSW has a proven history in the marine sector for the fabrication of small to medium sized aluminium ships. Innovation continues in further developing the process for aluminium fabrication, particular for corner and fillet welding, but the recent development of tools from several manufacturers that are capable of welding steel now opens up the prospect of applying the process to the fabrication and repair of larger steel ships and potentially, offshore structures such as oil production platforms, pipelines and wind turbine towers.

Considerable further work remains to be done to deploy steel FSW industrially:

- technically to develop the tools and welding process;
- with potential users of the process to tailor it to industry's needs;
- and with the classification societies to ensure it meets their acceptance.

Project RESURGAM provides an immediate route forward for the technical development programme, and TWI is already working with classification societies such as Lloyd's Register to address the requirements of the Certification process. The involvement of naval architects, designers and potential users of the process is now sought to ensure that the process meets the needs of industry.

ACKNOWLEDGEMENTS

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AUTHOR'S BIOGRAPHY

Stephen Cater, FRIN, MEI, AssocRINA, AWeldI, holds the current position of Principal Project Leader at TWI Ltd. He is responsible for managing the friction stir welding element of the RESURGAM project. His previous experience includes the development of the FSW process for steel and for thick section (>40mm) aluminium, as well as developing FSW for use under water and in oil. A metallurgist by training, and winner of the Richard Weck Award for his work on steel, Stephen has published over 20 papers on FSW.

FREIRE SHIPYARD´s FISHERIES SURVEILLANCE PATROL BOAT SABAH

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The fisheries surveillance patrol boat Sabah is one of the latest deliveries from Freire Shipyard at Vigo. With a length of 42 metres and a capacity of 16 crew members, the vessel, intended for the Public Authority for Agriculture Affairs and Fish Resources of Kuwait’s Marine Surveillance Department, will serve as a support unit for the Kuwaiti Navy’s patrol operations in its territorial waters, in the prevention of illegal fishing, as well as in search and rescue operations.

PICTURE: FREIRE SHIPYARD

The Sabah is the fourth patrol boat of this type delivered by the factory in Vigo during the 21st century, after the Arnomendi and Tarifa for the Spanish Navy in 2001 and 2003 respectively and Anna Kukurukaze Mungunda for Namibia in 2004. Founded in 1895 by Paulino Freire Piñeiro as Construcciones Navales Paulino Freire, the shipyard was originally responsible for the construction and repair of the fishing vessels of its own company. From the 20s of the last century, Freire began to build for different shipowners, manufacturing all the elements of the vessels within the shipyard itself, including its own patented steam engines.

PICTURE: FREIRE SHIPYARD

In 1958 the shipyard built its first steel-hulled ship. The construction of this ship lasted three years, but it represented a valuable learning and at the same time it forced the complete transformation of all production processes. Freire’s internationalisation came in the 1980s, with different contracts for South Africa, Morocco, Argentina and Mexico, and specialisation in the 1990s, with the construction of high value-added vessels: state-of-the-art freezer fishing vessels for Greenland and Holland, freezer vessels, oceanographic vessels and patrol vessels.

Four generations later, the Freire family is still at the front of the shareholding and management. During this time, Freire Shipyard has become an international benchmark in bespoke vessels destined for increasingly complex operations: Oceanographic research vessels, offshore support vessels, fishing vessels, sailing training ships, luxury mega-yachts, patrol vessels and tugs for the world's most demanding shipowners have been some of the vessels leaving the shipyard during the 21st century for shipowners, scientific organisations and navies in countries such as Norway, Denmark, the United Kingdom, Peru, Indonesia, Qatar, Kuwait and Saudi Arabia.

PICTURE: FREIRE SHIPYARD

PICTURE: FREIRE SHIPYARD

With a length of 42 metres and capacity for 16 crew members, the accommodation of the Sabah was entrusted to the Basque engineering firm Oliver Design, whose main challenge was to minimise the weight of all the components to the maximum so that the vessel could reach a speed of 30 knots. For this purpose, aluminium was used for both furniture and structural elements, and honeycomb panels that combine lightness and flexibility with strength.

From the bottom up, the boat is divided into three decks: the lower deck, with seven double cabins for the crew, the dining room, the office, rest areas and engine room; on the main deck, there are the captain's and chief engineer's cabins, the officers' mess, the galley and the refrigeration storeroom, as well as a small infirmary; and on the upper deck, the navigation bridge, with a 360-degree view.

The Sabah is powered by two engines of 2,880 kW each turning two fixed pitch propellers with which the vessel is capable of reaching a maximum speed of 30 knots. At the stern, the boat is equipped with a seven-metre in lenght semi-rigid rescue boat.

The boat, assigned to the Public Authority for Agriculture Affairs and Fish Resources, Kuwait Marine Surveillance Department, will serve as a support unit for the Kuwaiti Navy's patrol operations in its territorial waters, in the prevention of illegal fishing, as well as in search and rescue operations.

PICTURE: FREIRE SHIPYARD

Main characteristics:
Length: 42.00 metres
Beam: 7,70 metres
Draught: 2,40 metres
Crew: 16 persons
Installed power: 5.760 kW
Cruising speed: 28 knots
Autonomy: 14 days

QUALITY CONTROL IN TRAFFIC THROUGH THE PANAMA CANAL

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INTRODUCTION

In March 2021, the world kept an eye on the refloating of a large container ship that had run aground in the middle of the Suez Canal. The Ever Given (Figure 1), 400 m in length, was stranded diagonally in the middle of the Canal, leaving hundreds of ships waiting to be able to open the only possible route that facilitates the passage between Europe and Asia. The consequences of this catastrophe were colossal and had repercussions on the lack of supplies in many factories, which, following the good advice of Just in Time, delegate their logistics to the service of products on demand without taking up space with stocks. It is estimated that about 15% of the world's shipping traffic transits this canal and the disruption caused by this incident cost the Canal authorities more than 15 million dollars a day.

Figure 1. The Ever Given in the process of being removed in Suez

The Ever Given accident and the unchecked bet on ever larger vessels, with the sole aim of reducing costs, have made the importance that these shipping lanes have in the world economy in an increasingly globalized world fully topical.

Just like the Suez Canal, the other great passage that connects the Atlantic with the Pacific is the Panama Canal. In this case, works have been carried out that allow a widening and duplication of the narrow passages. The expansion of the Canal, with a third set of locks, places the Panama Canal in a competitive position to accommodate new ships, the so-called Neopanamax, which with a larger size (13500 Teus) have adapted to this new step width, reaching 50 m in length and 18 m in depth.

However, the ambition to increase the volume of new vessels and the lack of legislation to control their construction means that the expertise of the controllers (commonly known as canal pilots) is of great importance to avoid another similar catastrophe. Therefore, in order to manage in an automated and efficient way the transit of ships through channels such as Suez or Panama, it is necessary to apply statistical process control techniques, even more when the facilities are new and it is necessary to estimate the normal transit time and define the requirements of the company and customers. This is the case of the Expanded Panama Canal.

In June 2016, the Expanded Panama Canal was inaugurated. The final project involved the construction of a third set of locks larger than those made in 1914. This set of locks is located on the Atlantic side of the canal, on the east bank of the Gatún Locks. Another group of locks is located on the Pacific side, southwest of the Miraflores Locks. The expansion also included the dredging of both entrances to the Canal (Atlantic and Pacific), as well as the enlargement and deepening of the existing navigation channels in Gatun Lake and the deepening of the Culebra Cut. Unlike the locks built in 1914, the new ones have appropriate dimensions to maneuver the so-called Neo-panamax vessels, between 150,000 and 170,000 tons of displacement, as indicated in Carral et al. (2019). This interoceanic waterway connects 144 maritime routes reaching 1700 ports in 160 countries, positioning Panama as a transport, logistics and services hub(Figure 2).

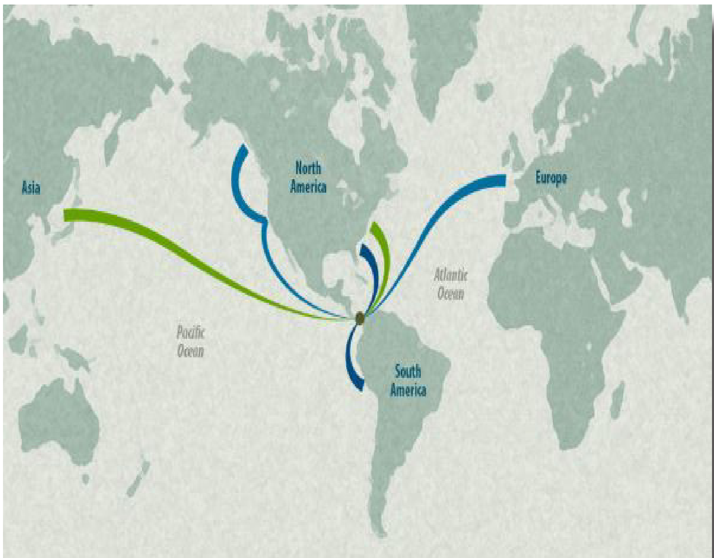

Figure 2. Panama Canal transit flow. Source: Georgia Tech Panama Logistics Innovation and Research Centre.

When analyzing the data related to the accumulated traffic through the Panama Canal, according to market segment and type of lock, in fiscal year 2020, it is verified that almost 75% of the total transits are Panamax-type ships, while the rest they are Neopanamax vessels. The most common vessels transiting the Panama Canal are Bulk Carriers, Container Ships, Chemical Tankers, Liquefied Petroleum Gas (LPG) carriers and Oil Tankers. Specifically, this paper studies Container Ships, LPG and those dedicated to the transport of Liquefied Natural Gas (LNG), given that they represent almost 80% of the transits of Neopanamax ships, disaggregated in 42.9%, 24.6% and 12.4%, respectively. Since its inauguration in 1914, around 1.1 million transits have been made through the Panama Canal, reaching 10.000 through the expanded Canal, since its opening in June 2016. This fact enables the application of techniques that are framed within the statistical process control, whose objective is the control, analysis and improvement of the process, in this case the transit of ships through the locks of the Expanded Panama Canal, being the objective of this work its proposal in this specific field.

PREVIOUS STUDIES ON LEARNING MODELS IN THE CANAL

The process of transit through the expanded Panama Canal consists of a succession of repetitive processes. As the number of repetitions and the experience of the staff and organization increase, a reduction in the time and effort required to carry out the transit of ships through the Canal could be expected. This reduction in time would be due to the performance of work in an increasingly efficient way, mainly due to a phenomenon defined as "learning", whose graphical representation is called, in turn, "learning curve". Therefore, the visualization, statistical modeling and estimation of this curve defines the learning process in a process, being limited in this case to the pilotage and maneuvers of the Canal Authority to carry out the transits of ships.

Learning curves are based on the premise that organizations, like people, do their jobs better as these are repeated. Individual learning is related to the repetition of a process and the acquisition of the corresponding skill from experience. On the other hand, organisational learning is also the result of practice, related to management tasks, the use and type of equipment and the design of products and processes, among others (Lefcovich, 2003).

Precisely, at Carral et al. (2021) a methodology for studying individual and organizational learning is proposed in the particular case of the Expanded Panama Canal. To this effect, transit times through locks in the period 2016-20 were studied. As results, the learning curves of the container ships, LPG and LNG, were estimated from the study of the transit time through each lock, taking into account the direction of the route (Figure 3). This study concluded that container vessels tended to make slower transits along the locks, to some extent due to their size. On the other hand, transits whose starting point was the ocean also tended to be slower. Thus, the direction of transit significantly affects the total transit time across the Expanded Channel.

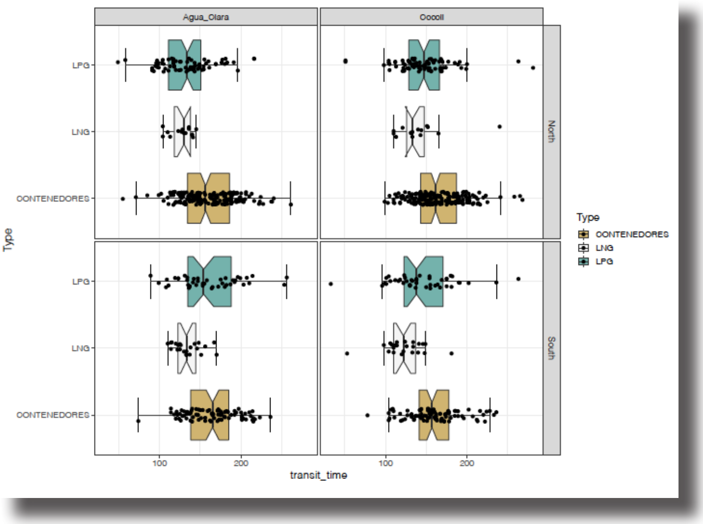

Figure 3. Box plots for transit time depending on the combination of vessel type, lock and direction of transit levels.

On the other hand, in Carral et al. (2019), a model that could predict the total time to cross the Extended Channel was estimated using models based on Support Vector Machines (SVM). The following variables were also analysed by applying multivariate regression models, in addition to identifying the most influential variables on transit time: transit direction, vessel type, vessel length (LOA) and experience.

QUALITY CONTROL FOR THE PANAMA CANAL

The control of the passage of vessels through the Canal can be assimilated to an industrial process with the variations that may have the skill of the pilots, the type of vessel, the climate at the time of passage, etc. In this sense, control charts are an essential tool to verify whether a process is under control (absence of anomalies) and to measure its ability to meet the company's specifications.

The quality control is carried out in two phases. In the first phase, called Phase I, the natural lower and upper limits corresponding to the control charts are estimated. The starting hypothesis for its application are normality and independence between observations. Once the natural control limits have been calculated for this Phase I, an analysis is made of the process capability to meet company, standard or customer specifications. In other words, the capacity indices are calculated by comparing the specifications given by the channel authorities, with the real variation range of the critical variable for the quality of the process to be measured (CTQ). The capability analysis tells us whether or not the process is capable of meeting the specifications or whether or not an improvement plan needs to be implemented. Finally, in Phase II, the passage times of the channel are monitored based on different variables of interest and possible anomalies are automatically controlled in order to find faults and improve the process.

For the analysis, data corresponding to the transit times of different types of ship (the most common in the expanded Canal) will be taken, in particular, through the Cololí and Agua Clara locks, in the directions from Atlantic to Pacific (South) or from Pacific to Atlantic (North). The operations at each lock are taken in chronological order, in the interval from 2016 to 2019. All calculations are implemented using the R statistical software, specifically through the use of the qcr (Flores et al, 2021) and qcc packages.

BAROQUE TRAINING SHIP TRANSIT ANALYSIS

The Panama Canal Authority (ACP) has chartered a vessel, called Baroque, which has been used to train pilots for the passage through the new locks of the Expanded Panama Canal. A specific lock has been chosen and transits have been carried out by different pilots. The results can be used to estimate which is the distribution of transit times through a lock. From this distribution, we can define a maximum specification limit above which transit is penalised. From this upper limit, it can be established whether or not the ACP is able to meet its own specifications. Figure 4 shows a gradual change pattern of an asymptotic type, whose assignable cause is the learning of the organization. The proposal is to use control charts and capability analysis to monitor, analyse and continuously improve all CP processes related to vessel transit.

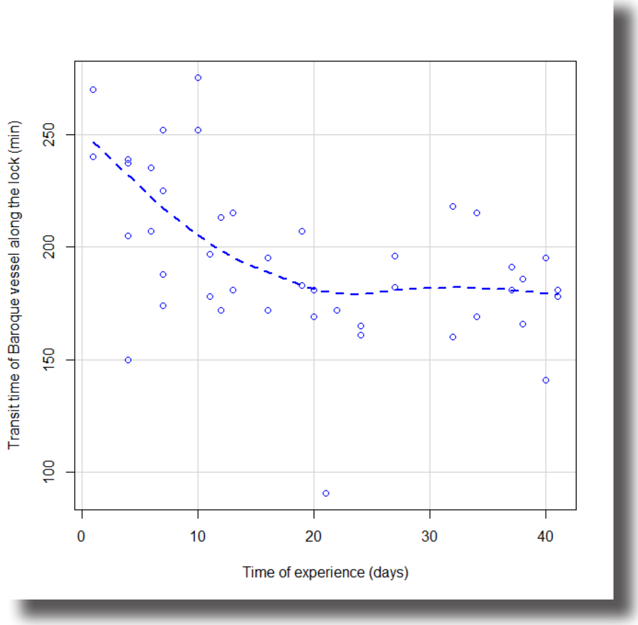

Figure 4. Relation between the days of experience of the pilots and the times of transit in the Canal with the Baroque data sample. Fitting a non-parametric Loess regression model.

The last 21 observations are taken, corresponding to the transit time saturation zone (Figure 4), Shewhart control charts are applied for individual measures and are found to be under control, there is no assignable cause for the transit time variation other than those due to the randomness of the process itself (Figure 5a). This preliminary study allows to establish a tentative specification limit for the transit time through each lock, in fact, since the process to be studied is new, an upper specification limit (USL) has not yet been defined by the company. This limit should indicate whether or not the process is capable of meeting specifications, and help to undertake improvement actions or to make the decision to proceed to penalise a certain transit. Figure 5b shows the transit time distribution, which can be adjusted to a normal distribution and, as such, the 0.999 quantile can be taken, for example, as a tentative USL, in this case 250.6 min.

The next step is to control the passage of ships through the Expanded Canal between 2016 and 2020, in order to detect learning patterns and possible anomalies, providing information to take improvement actions.

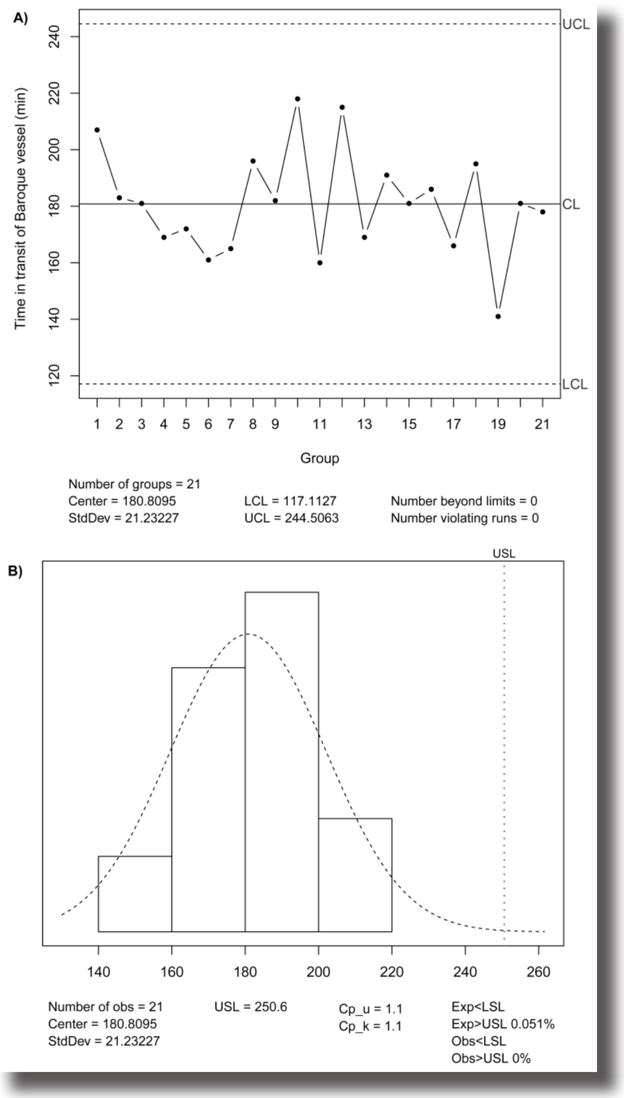

Figure 5. A) Control chart for transit time using the last 21 transits of the vessel Baroque. B) Histogram and density function assuming normal distribution of transit time, upper specification limit (USL) and capacity analysis.

As an application example, the transit times through the Agua Clara lock in a southerly direction, from Atlantic to Pacific, are studied. At this point, it is important to note that, since transit time follows a different distribution according to lock, type of ship and direction, it is necessary to study each combination of factors separately. Figure 6a shows the histograms of the transit time of southbound container ships through Agua Clara, taking the first month since the opening of the Canal, on the one side, and the routes from 2017 onwards, on the other side.

The difference in averages between the two samples is 2.5 times the typical deviation of the transit times in the first month, there is a relatively significant learning effect.

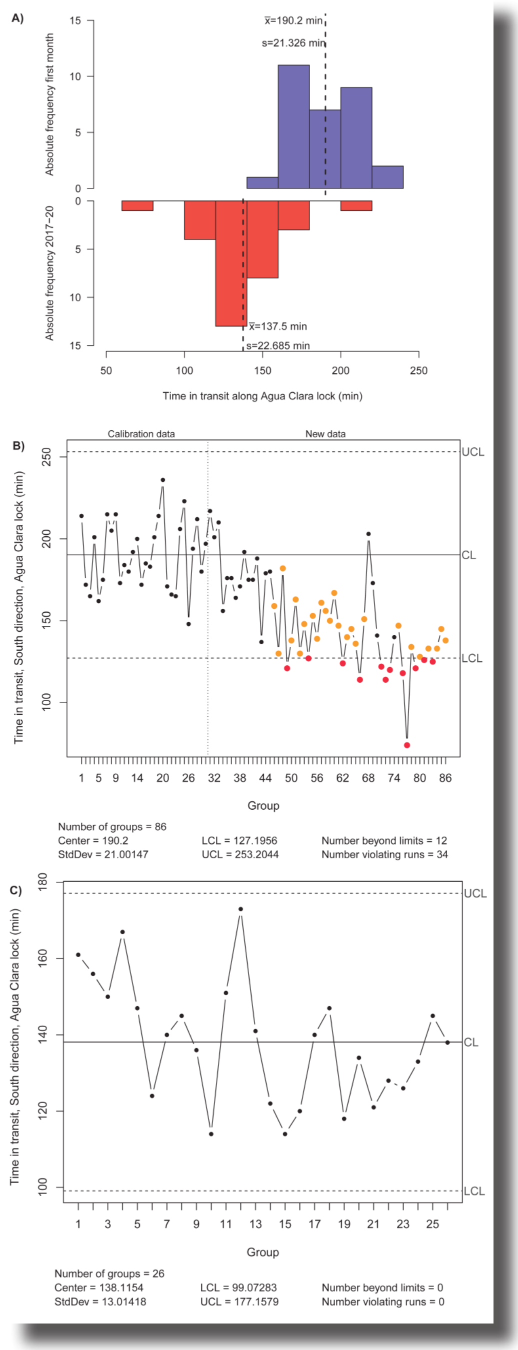

Figure 6. A) Histograms of the distribution of transit time the first month of operation of the Canal and from 2017 onwards. B) Transit time control chart (calibrated and monitored sample). C) Control chart for transits from 2017 onwards.

Figure 6b shows the application of control charts for individual measures, taking as a calibration sample the transits carried out in the first month since the opening of the Canal. Natural control limits are estimated and transits since 2017 are monitored. As a result, it identifies a pattern of gradual level change, due to the effect of learning. New control limits are therefore taken from sample 23 (Figure 6c). As can be seen the process is back under control. As you can see, the process is under control again. Once the process is obtained under control the next step is to see if it is capable to meet the specifications of the company, the standards or the customers. For this purpose, capability indices are calculated using an upper specification limit of 250.6 minutes.

In particular, the index: $C_{pu}=\frac{USL-\hat{\mu}}{3\hat{\sigma}}=2.881$

(being $\hat{\mu}$ the estimation of the average and $\hat{\sigma}$ the estimation of the standard deviation) that is, the process would be able to meet specifications at a higher level than the corresponding to a Six Sigma level, with practically no traffic expected with a time higher than the USL.

CONCLUSIONS

Statistical quality control is essential for decision making in any organisation. In the case of the study of maritime traffic, the application of quality control is of great help to improve transit times, allowing to measure processes, control them and propose improvements based on experience and data

WITH THANKS TO

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HEAT EXCHANGERS. TYPES AND APPLICATIONS.

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1. INTRODUCTION

In the majority of installations in which different forms of energy come into play, heat transfer processes between fluids usually play a fundamental role in their operation, both from the point of view of their production process and when it comes to managing variables such as energy efficiency or carbon footprint.

Heat transfer processes, including cooling, heating, vaporisation and condensation, occur in what are generally known as heat exchangers, through the concurrence of heat transfer mechanisms by convection and conduction and, in certain cases, by radiation as well.

When selecting and sizing a heat exchanger without phase change, with phase change or a combination of both, it is necessary to take into account that a large number of variables come into play, highlighting the physico-chemical properties of the fluids, the flow conditions, the existence of chemical reactions, the properties of the exchange surface, if any, etc. In any case, the aim is to find a solution that allows the maximum heat transfer with the minimum heat exchange surface. It is therefore difficult to establish a single criterion for the broadest possible typology of the various heat exchangers found in different industrial and naval applications. The following is an attempt to list a series of characteristics that make it possible to mention most of these typologies.

2.- CLASSIFICATION CRITERIA

2.1- Heat transfer mode.

When it comes to transferring energy from high temperature gases to another fluid, depending on the predominant **mode of heat transfer** from the gas, it is possible to dispose of convection, radiation and mixed heat exchangers. The first ones are characterised by the fact that the stream temperatures are not excessive and the fluid streams flow over the surfaces. In gas recovery boilers on vessels with internal combustion engine propulsion, the energy of the exhaust gases is used for steam generation on surfaces where convection predominates. Similarly, in combined cycle power plants, steam generation from the gases coming from the gas turbine takes place in convective type exchangers.

Radiation exchangers are those that are located in the presence of combustion, as occurs with the waterwalls in the furnace of a boiler, or in wall-type superheaters that “see” the flame directly. They are characterised by high heat flows per square meter, therefore, to protect the exchange surface from the high temperatures, a fluid is internally arranged in phase change or circulating at high speed, in order to increase the internal convection coefficient.

In mixed heat exchangers, the two modes of heat transfer coexist with a surface disposition in the presence of the flame while allowing the external circulation of gases “bathing” the surface. As an example, it can be mention the platen superheaters that can be arranged in the ceiling of the furnace of a boiler or inverted U superheaters as in the case of Mitsubishi marine dual-fuel- boilers.

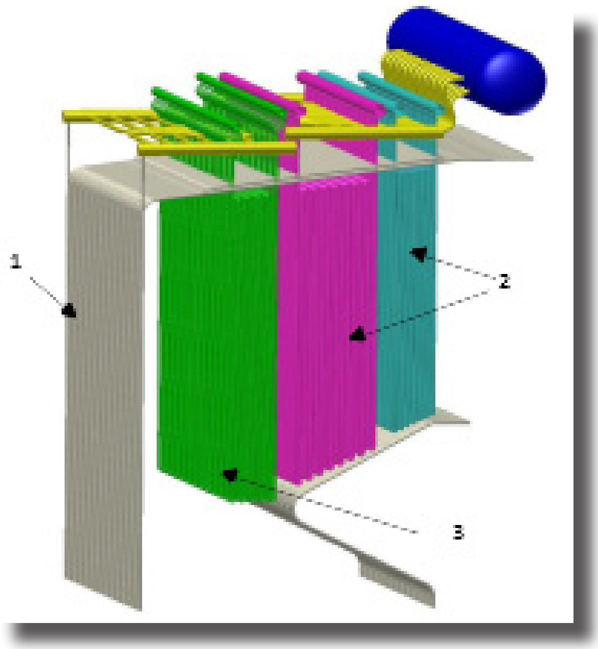

Figure 1.- Heat exchangers in a steam generator with predominance of transfer by radiation (1), convection (2), convection-radiation (3) [1].

2.2.- Flows disposition.

Considering the circulation of fluids, a distinction is made between **parallel flow, counter flow, mixed and crossed exchangers**. In parallel-flow heat exchangers, the streams flow in the same direction, resulting in a decreasing temperature gradient in that direction and an almost constant average exchange surface temperature over the entire length of the heat exchanger. In counterflow heat exchangers, the streams flow in opposite directions, maintaining a more stable temperature difference between streams and a higher surface temperature on the hot side of the heat exchanger. Likewise, it allows to lower the temperature of the hot fluid, below that of the outlet of the cold fluid. In mixed flow, the two previous configurations are combined, generally seeking a lower surface temperature on the hot side, by means of a parallel configuration to later dispose a counter flow section to increase the temperature difference between the streams.

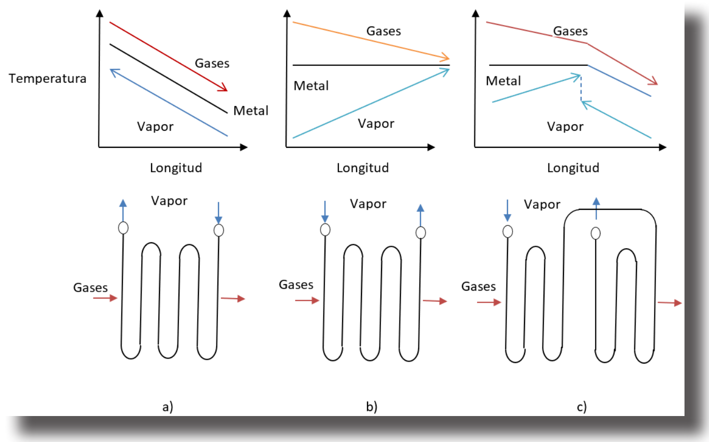

Figure 2. Temperature variation of streams and exchange surface according to counterflow (a), parallel (b) and mixed (c) configurations.

In cross-flow exchangers, the currents flow forming a right angle.

In certain applications, one of the streams in liquid state is provided in the form of a vertical or horizontal falling film or by keeping the exchange surface permanently submerged, in applications where boiling / condensation occurs.

2.3.- Existence of exchange surface

Regarding the availability or not of an intermediate surface that separates the fluids that exchange heat, we can speak of **closed or surface exchangers and open or mixing exchangers**. The first have the advantage of allowing heat exchange between fluids of different natures without mixing between them. They are the most widespread and have numerous configurations that will be commented on through other criteria.

In the case of open or mixing heat exchangers, the heat exchange is associated with the direct mixing of fluids at different temperatures inside the exchanger itself, with no surface separating them. As an example, we can cite the so-called degassers or deaerators that are usually used in steam power cycles, where the flow coming from the condenser increases its temperature and undergoes a process of thermal desorption of the air present in the liquid phase, through the supply of a flow of steam extracted from the medium-low pressure turbine.

In this way, the performance of the installation is increased and corrosion is greatly limited.

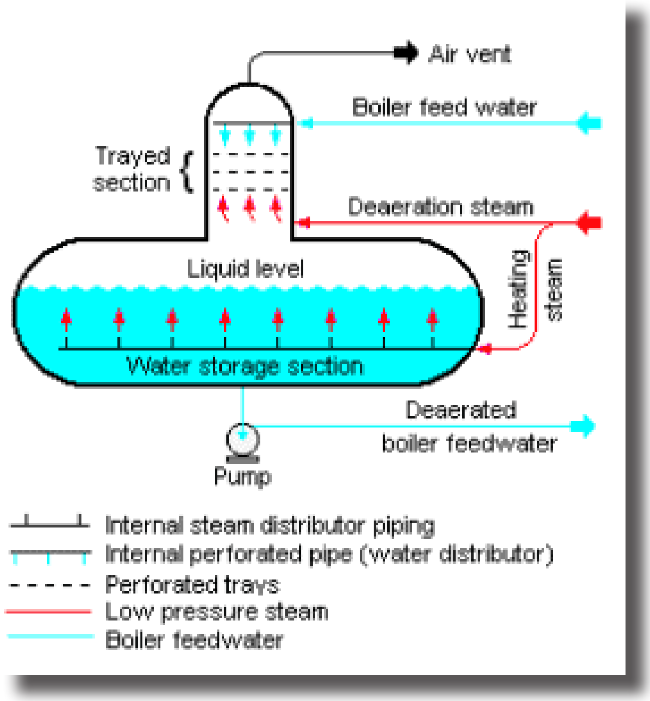

Figure 3.- Mixing or open exchanger. Application as a tray degasser [2].

2.4.- Disposition of the exchange surface.

When considering the **disposition of the intermediate surface** in closed heat exchangers, countless variants arise.

Recuperative exchangers are those in which the exchange surface remains static and are the most widespread in practice. They have the advantage of not allowing mixing between the fluid streams involved.

In regenerative heat exchangers, the exchange surface passes alternately through the flows of the two gas phase fluids, thanks to the rotation of the surface or the rotation of the flow ducts. They are used in air-conditioning systems, generally for energy recovery from the return flow and in thermal power plants, where the Ljungstrom model, with surface rotation, and the Rothemühle model, where the surface is fixed and the ducts rotate, stand out. In this case, the energy of the gases leaving the boiler is used to preheat the combustion air, increasing thermal efficiency. They have the advantage, with respect to recuperative systems, of reducing the weight and volume of the equipment, but with the disadvantage of the inevitable leaks between flows.

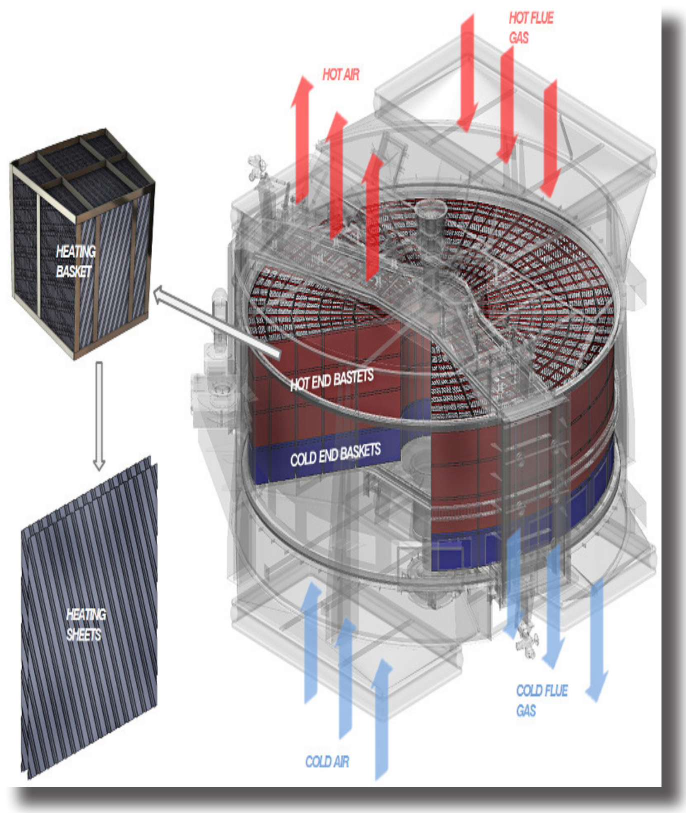

Figure 4.- Regenerative heat exchanger with rotation of the exchange surface [3}.

Considering the **shape of the exchange surface**, we can mainly distinguish between **flat and cylindrical surfaces**, which can also have fins of very different shapes that, when they reach high densities, give rise to **compact heat exchangers**. The latter are mostly applied in cases where one of the flows has a low convection coefficient, such as in the case of gas phase flows. These compact exchangers with flat surfaces with corrugated fins, strips, offset strips, etc., allow the arrangement of more than two fluid flows, as in the case of the “cold box” exchanger used in re-liquefaction systems in LNG carriers or in land-based installations.

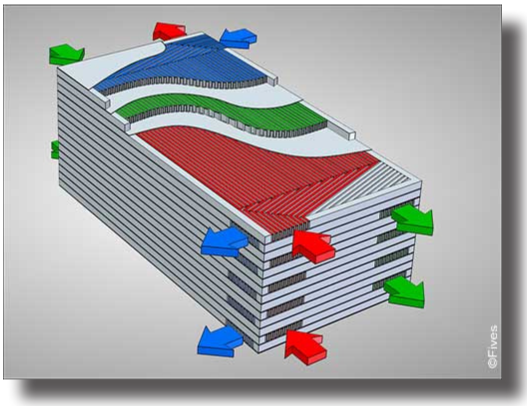

Figure 5.- Corrugated plate heat exchanger, compact, recuperative, with exchange between three streams [4].

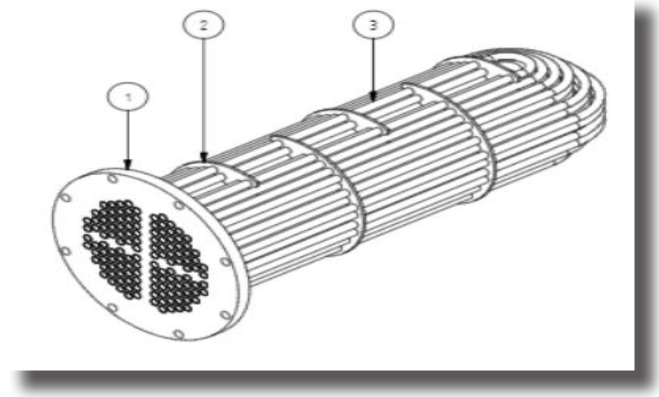

Figure 7.- Tubular U-shaped bundle with triangular arrangement showing 1-plate; 2-deflector or baffle; 3-tube bundle.

Special mention should be made of **plate heat exchangers**, in their joint or welded plate variants, which are generally characterised by high heat transfer coefficients due to the high turbulence induced by the corrugated geometry, at the cost of higher pressure losses.

Among the exchangers with a **cylindrical surface**, those with **shell and tube, concentric tubes, thermosiphon tubes or heat pipes** and **spiral wound tubes** stand out.

The **shell and tube heat exchangers** have tubular bundles in a triangular arrangement at 60 or 30 °, square and at 45 °, in a straight or U-shaped bundle, and with one or more passages. There is a wide variety of typologies that are included in a reference standard drawn up by the Tubular Exchanger Manufacturers Association (TEMA® STANDARDS), based on the type of heads (front and rear end)and shell.

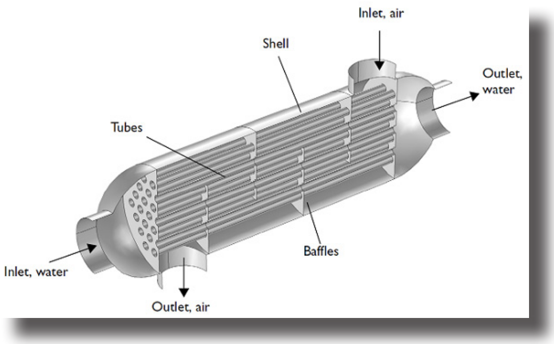

Figure 6.- 1-1 Shell and tube heat exchanger (1-Shell -1Tube pass) [5].

Those with concentric tubes or double tubes are applicable for reduced surfaces, without phase change and when the fluids are at high pressures.

The heat pipes are sealed at both ends and contain an exchange fluid (water, methanol, freons, etc.) which suffers a cyclic process of vaporisation on the hot side of the pipe, moving towards the cold side where it condenses, returning again to the hot side. They are usually disposed in the form of a horizontal tubular bundle, with or without fins, with an outer divider plate to separate the hot and cold flows. The section towards which the vaporized fluid circulates to be condensed may have a certain inclination of 5 or 6 degrees to favor the return of the condensate by gravity towards the hot side. They have applications in refrigeration of electronic equipment, air conditioning, air preheaters in boilers, etc.

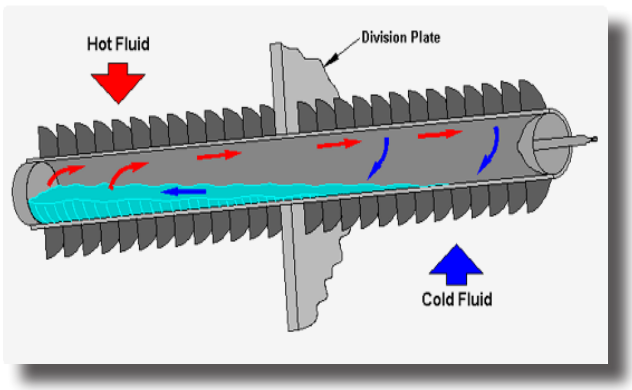

Figure 8. Thermosyphon tube where the circulation of the steam generated on the hot side, towards the cold side is represented. Once condensed, it returns by gravity to the hot side [6].

Finally, **spiral tube heat exchangers** have numerous applications, including cryogenics and crystallisation. Like compact heat exchangers, they allow heat transfer between more than two fluid streams, achieving large heat exchange surfaces when very small diameter tubes are used.

As already anticipated, the task of establishing as complete a classification as possible involves taking into account a wide range of criteria. However, there are applications which require ad-hoc designs and which are particularly complex to include in any of the above categories.

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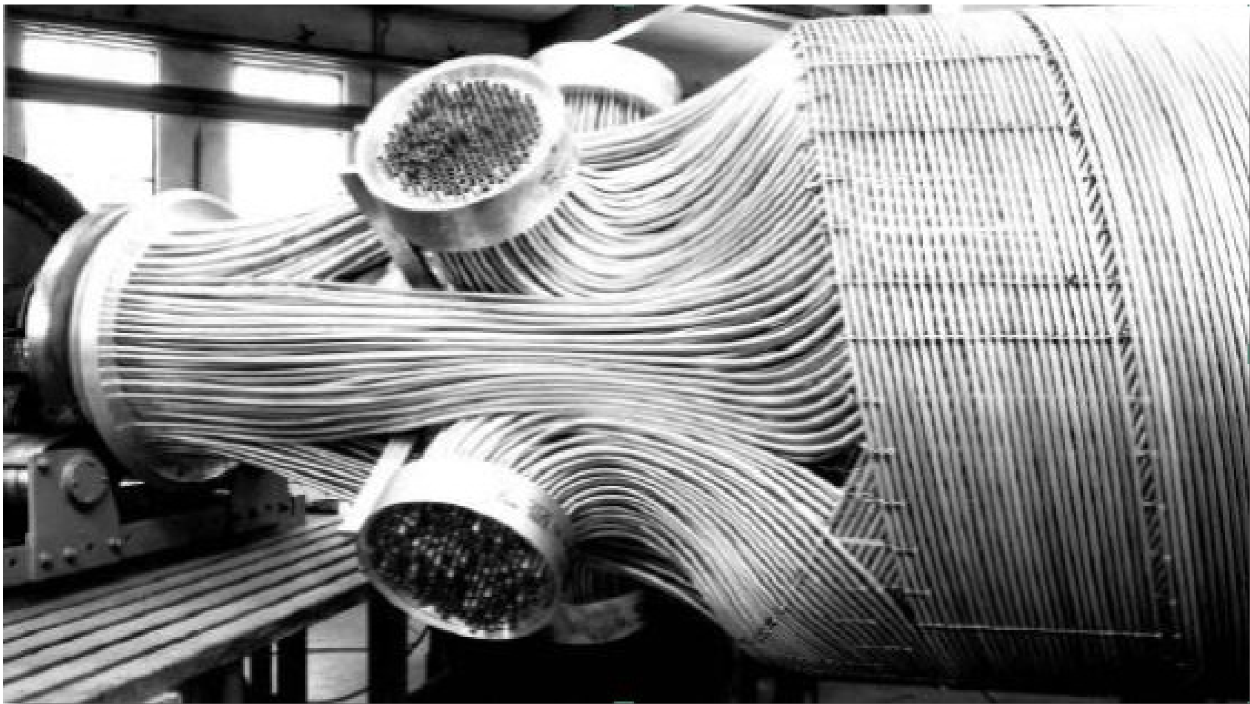

Figure 9. Linde spiral tube heat exchanger for LNG reliquefaction [7].

Interview with: Cándido da Silva // Managing Director of:

REPARACIONES NÁUTICAS AMURA S.L.

Q: Amura reparaciones naúticas was created in 2003, to provide a service mainly to the nautical sector. In production it uses the latest technological advances and offers innovative and vanguard products for the manufacture of parts in any type of composite (GRP, Epoxy, Vinylester, etc...) such as infusion, casting, RTM, etc...

It began its activity as a nautical carpentry and, in a short time and due to the satisfaction of its clients with the work carried out, it started to offer other types of services, and today it is able to produce composite parts and boats, from the preparation of the mould to the final piece, both of its own design and supplied by the client.

Cándido Da Silva (Managing Director of Amura Reparaciones Náuticas) answers our questions today:

• Q: How were your beginnings?

I started as a freelance in the naval sector, I had an enormous interest in the field of Nautical from the beginning and I decided to train myself. Then I took the leap and that is when I created the company, starting with carpentry work, but always with the idea of providing coverage and comprehensive service to my customers, covering more jobs and lines of activity. We started working with composites, creating moulds and making structures, something that has a lot to do with the carpentry trade, also with painting work; and little by little I started to contract and to be able to offer more services as a company in addition to the specialised carpentry.

• Q: What was the axis of your activity at that time?

At that time focused on carpentry and joinery. Changing teak, for example, and with all kinds of interior reforms, maintenance...

• P: At present, do you continue with the same activity or has the company diversified its business lines?

We cover integrally all the works that have to do with composite structures, we also continue with the carpentry for refits, and we have a team of painters of total reference. We have gone from being carpenters to being painters of yachts and mega-yachts, this would be our core business. We realised that there was a lack of this type of specialist, and we decided to also focus on this activity because we believe that given the characteristics of the sector in our environment, there will be opportunities, which is where the market is evolving towards. Every day we receive more and more requests for this type of highly specialised work.

We started training our own staff and moving towards this activity. Since the beginning of the year we have started to manage a dry dock for yachts in Vigo (in the Marina Davilasport facilities) with travel up to 70 Tn, the facilities also have one of the few cabins for painting yachts and/or annexes, it is 29 m long x 8 m wide x 7 m high, with programmable heating and extraction.

• Q: What has been the recipe for keeping up viable and competitive in the market?

Clearly there is a basic rule: the first thing is to provide quality and service, there is no other recipe. For example, with service, which often has a bad reputation in terms of delivery times, meeting these deadlines, being very rigorous with these issues...

• Q: What is the typology of the company's customers and its market?

Our clients are above all private individuals, they are the bulk of our clientele. People who have boating as their hobby, whether sporting or recreational. However, we also work for important companies such as: SeaDrone, Freire Shipyard...

In terms of our market: recreational boating and also professional boating.

• Q: In an economic context where globalization prevails, are your main competitors locally or foreign?

In our case, at the repair level, the competition is local. In contrast, at the construction level, it is international. For example, with the construction of the new UX-R boat for Titan Yachts, as a shipyard, the competition would be at international level, which is only where this type of boats are manufactured. This type of boat is only being made in northern European countries, Italy, ... it is something very particular, focused on leisure or as a support boat for mega yachts, fully manufactured and customised by Amura. It is a boat of 9 metres in length with two 200 HP outboard engines, a carbon fibre hard top, in the bow there is a seat on both sides for 3 people, in each one with a table and convertible into a solarium and a complete solarium in the stern, a bathroom with a height of 190 cm, and in the hard top module, a fridge adapted for this unit, a grill. Elements such as the handrail and the bow´s top have been made specifically with suppliers in our area. It is a boat made entirely by our company, from moulds to final parts, including the laying of the teak and assembly of elements. And counting on companies in our area for the manufacture of stainless steel, wood and electrical and electronic assemblies.

• Q: How does Amura differ from its competitors?

In the specialisation, very clearly in each of our departments. We try to differentiate ourselves with specialisation and quality. One thing leads to the other somehow, by being so specialised you are also offering quality, delivery times, quality of materials, etc.

• Q: How do you see the future of nautical construction and repair, with regard to your area of activity?

We believe that in our area of specialization in particular very well, with prospects for growth. In Shipbuilding, competition is outside, with French and Italians accounting for 60% of the business. We are optimistic, there are not many places that can get the production that Galicia once had in fiber boats. It worked here, there is capacity to get to those levels. Therefore, Galicia has a future because we have the capacity to produce and absorb foreign markets; we may not have the capacity to market, but we do have the capacity to produce.

There is a future in Ship repair because we see that the fleet is growing, and we also believe that the average lengths are growing. Here there is a tremendous lack of knowledge of our environment, of the estuaries (Rías Baixas/Rías Altas), we do not value what we have, the pleasure of sailing in an estuary... in other places they would be sailing all year round. More and more foreign clients are sailing here, there are people from northern Europe who prefer our climatology to the Mediterranean, the food, etc. The tourist promotion of Galicia as a place for sailing is very little, we are not getting the most out of it so far and there is no culture of nautical sports as developed as in other places. With the possibility of renting, this can change, in other places it has worked, with affordable prices things that were otherwise unattainable can be enjoyed.

• Q: Has your sector changed much since you started?. How has it changed?

When we started we were in the middle of a boom, a time of economic prosperity. We went from madness to common sense in 2008, it stopped and we saw how boats that could not be maintained began to be sold. It was clear who could hold their own, the 2008 Crisis somehow selected the competition. It was when several shipyards closed, we were able to organize ourselves and achieve a stabilised situation. We went from the boom that I was talking about to a more normalized situation since then, just like the nautical park.

Competence is also something to take into account, its evolution, prices were thrown down, and this harmed everyone, to the sector and its quality levels, we consolidated ourselves thanks to this, competing on price, but above all with quality.

• Q: To what extent has the use of new materials such as composites influenced your sector?

Composites, polyester, are not new, boats have been made since the 70s. There are at present developments in these types of materials and resins. Now, for instance, with bioresins, which are the future. We want to be at the forefront of these materials, these ecological resins are very interesting for new horizons, and we are the only ones working in Galicia with this type of new materials. In terms of moulds we are a reference, in this we have not changed, we use all our experience in carpentry to make any type of mould. It changes because now we make complete boats, we are a shipyard, and from repair we go to major refits and now to construction and complete customisation.

• Q: The situation created by COVID-19, with the paralysis and slowdown of economic activity, how has it affected you?

At a company level it is not something that has affected us, we have not suffered too much, we have continued with a similar activity. Since it was not possible to travel, foreign customers failed, but nationals did use their ships a lot. It is a very good way to create your own bubble and also be able to enjoy it in unbeatable conditions. In addition, we have been told by companies in the sector that sales and rentals have worked very well, with more sales than ever before. Above all, the more affordable vessel type and the possibility of chartering.

Moreover, we decided to start this new project as a shipyard. To diversify and be able to maintain our structure all year round. Our staff is like a family, and we wanted to be able to cover the months with less workload in repairs with this type of construction activity, to ensure work every month of the year and to keep our workers. In addition to being a challenge and a motivation for the company.

• Q:Now that the health authorities have indicated that we are on the path to return to normality, what are your short-term prospects?

In the short term we are focusing on generating work for the post-covid stage. The clients have made reforms in their boats during the whole period of pandemic, maintenance, etc., our main concern was to occupy the following 6 months, to arrive at the end of the year with a workload, since towards December begins for us the busiest period in reforms, repairs, customisations, maintenance...

• P: And in the medium and long term?

On an international level, in addition to what I am talking about as a shipyard, one of our potentials is the painting of ships. Fillers and painters for yachts and megayachts. This is our strongest point and where we are going to orient ourselves towards. This is what is needed, not only in Galicia, we believe that this is where the sector is heading, for example, in Vigo, one of the driving forces in this sense. We are committed to creating a solid structure as a company for this model.

We want to serve a demand that we consider there will be, perhaps not so obviously now, but for our part we are pushing and betting heavily so that the contract remains in Galicia. We have collaborations and working agreements with reference companies.

As I said, our work is seasonal. That is why with this new boat that we have created, different, very export-oriented, we are going to achieve the desired stability for our team of people from August to February.

THANKS FOR YOUR COLLABORATION:

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