ELECTRIC AND AUTOMATIC MARINE LOADING ARMS

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BRAS DE CHARGEMENT MARINE ELECTRIQUE ET AUTOMATIQUE

L'électrification des produits est une tendance globale dans l'industrie et le remplacement des centrales hydrauliques traditionnelles par des systèmes électriques devient de plus en plus courante. L'électrification est observée dans beaucoup d'industries, y compris les transports (par exemple, les véhicules électriques, les systèmes de contrôle des avions), les appareils électroménagers ou l'industrie de l'énergie. Cette tendance a été stimulée par les progrès technologiques et une demande croissante de produits plus efficaces et durables.

Cette présentation expliquera comment Technip Energies (T.EN) a transformé sa technologie bien connue des bras de chargement marine (Marine Loading Arms : MLA) en une solution de transfert innovante.

À ce jour, les entraînements hydrauliques sont exclusivement utilisés pour actionner les MLA. Les opérations telles que le verrouillage/déverrouillage, la connexion/déconnexion au/du manifold du navire, sont contrôlées manuellement par un opérateur à l'aide d'une télécommande.

Bien que cette technologie ait fait ses preuves, les systèmes hydrauliques restent une source potentielle de pollution de l'environnement. Le MLA électrique et automatique (e-MLA automatique) est par essence un produit plus durable et efficace étant donné que :

- Le réseau de tuyauterie hydraulique complexe et étendue inhérent aux entraînements hydrauliques est éliminé, ce qui facilite le montage et la maintenance.
- Ce MLA utilise des technologies de pointe telles que des capteurs, des algorithmes de contrôle pour permettre des mouvements automatiques, fluides et précis.
- Il s'agit d'un produit numérique dès la conception, permettant l'enregistrement de données d’opération, l'évolution du logiciel tout au long du cycle de vie du produit et la maintenance prédictive.
- L'automatisation réduit le niveau d'intervention humaine. Le e-MLA automatique est l'un des éléments de l'opération de jetée entièrement automatisée qui permettra à moyen terme des opérations autopilotées.

Loading Systems a terminé un programme de développement pour concevoir et qualifier un bras électrique (e-MLA) avec le contrôle « Auto Drive ». Une unité pilote est en cours de fabrication et débutera sa mise en route au second semestre 2023 sur le site de T.EN Loading Systems. Elle comprend cinq bras GNL de 60' - un réel et quatre autres simulés - avec le système de contrôle complet, y compris le mode automatique et des fonctions avancées de monitoring.

Cette présentation aborde le développement de l'e-MLA, le développement du mode Auto Drive et la qualification des briques technologiques clés requises. Les avantages de l'e-MLA automatique du point de vue de la conception, de l'exploitation, du coût et de la durabilité seront abordés.

SUMMARY

Electrification of products is a global trend in the industry and replacing traditional hydraulic power units with electrical systems is becoming increasingly popular. Electrification is being seen across a wide range of industries, including transportation (e.g. electrical vehicles, aircraft control systems), home appliances or the energy industry. This trend has been driven by advances in technology and a growing demand for more efficient and sustainable products.

This presentation is going to address how Technip Energies (T.EN) has reshaped its well-recognized Marine Loading Arms (MLA) technology into an innovative transfer solution.

As of today, hydraulic drives have exclusively been used to power MLAs. As a matter of fact, all driving-related operations such as parking/unparking, connecting/disconnecting to/from the ship manifold, are manually controlled by an operator using a remote-control unit.

Despite this technology has proven records, operating hydraulic systems is a threat to the environment and the local marine life. The automatic electric MLA (automatic e-MLA) is by essence a more sustainable and efficient product and a pivot in the business as:

- The complex and spread hydraulic tubing inherent to hydraulic drives is eliminated, easing assembly and maintenance,
- This MLA uses advanced technology such as sensors, control algorithms to enable automatic, seamless and precise movements from parked to connected attitudes,
- It is a digital by inception product, opening for operations datalogging, software evolution along product lifecycle and predictive maintenance,
- Automation reduces the level of human intervention. The automatically MLA is one of the pieces in the fully automated jetty operation which will enable completely unstaffed operations at medium term.

T.EN Loading Systems has completed a development program to design and qualify an e-MLA with the Auto Drive control. A pilot unit is under assembly and will start commissioning second half of 2023 in T.EN Loading Systems facilities, to demonstrate the solution. It features five LNG 60’ e-MLA – one real and four other simulated – with the full control system package, including automatic mode and advanced condition-based monitoring functions.

This presentation addresses the development of the e-MLA, the development of the Auto Drive control and the qualification of the required key technological bricks. The benefits of the automatic e-MLA from a design, operational, cost and sustainable perspective will be covered.

1. CONVENTIONAL MARINE LOADING ARM CONTROL

To date, hydraulic drives have exclusively been used where there is a need for a powered Marine Loading Arm (MLA).

Purpose of the powered manoeuvring system is to allow the manoeuvring of the MLA from its parked position to its connected position and vice versa.

The three main rotary motions of the MLA, slewing, Inboard Arm (IA) luffing and Outboard Arm (OA) luffing, are actuated with hydraulic cylinders (refer to Figure 1).

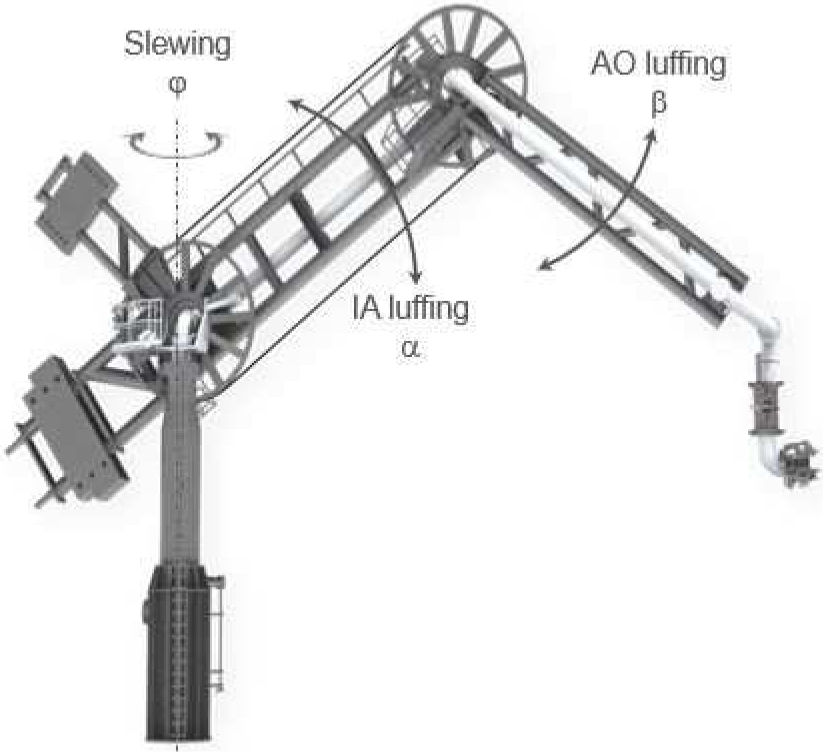

Figure 1: Powered rotation motions of an MLA

In the vast majority of cases, a Hydraulic Power Unit (HPU) provides a constant hydraulic flow. The hydraulic flow to each actuator is controlled with a basic solenoid type valve (i.e. on-off). A single-speed motion is then achievable (i.e. “stop” or “full speed”). The HPU may be fitted with a two-level flow setting (“low” and “high”) allowing the operator to manoeuvre the MLA at a reduced single-speed motion.

The operator controls, using a Remote Control Unit (RCU), each rotary motion – slewing, inboard arm luffing and outboard arm luffing – to move the MLA connection flange at the desired position e.g. for connection/disconnection to/from the ship manifold. ln practice, control of the MLA connection flange position is not straightforward in that the operator needs to get intensive training to get familiar with the kinematics of the MLA. Furthermore, as the movements are generated by actuators with on-off control at a fixed speed, the MLA movements are jerky and inexact (refer to Figure2)

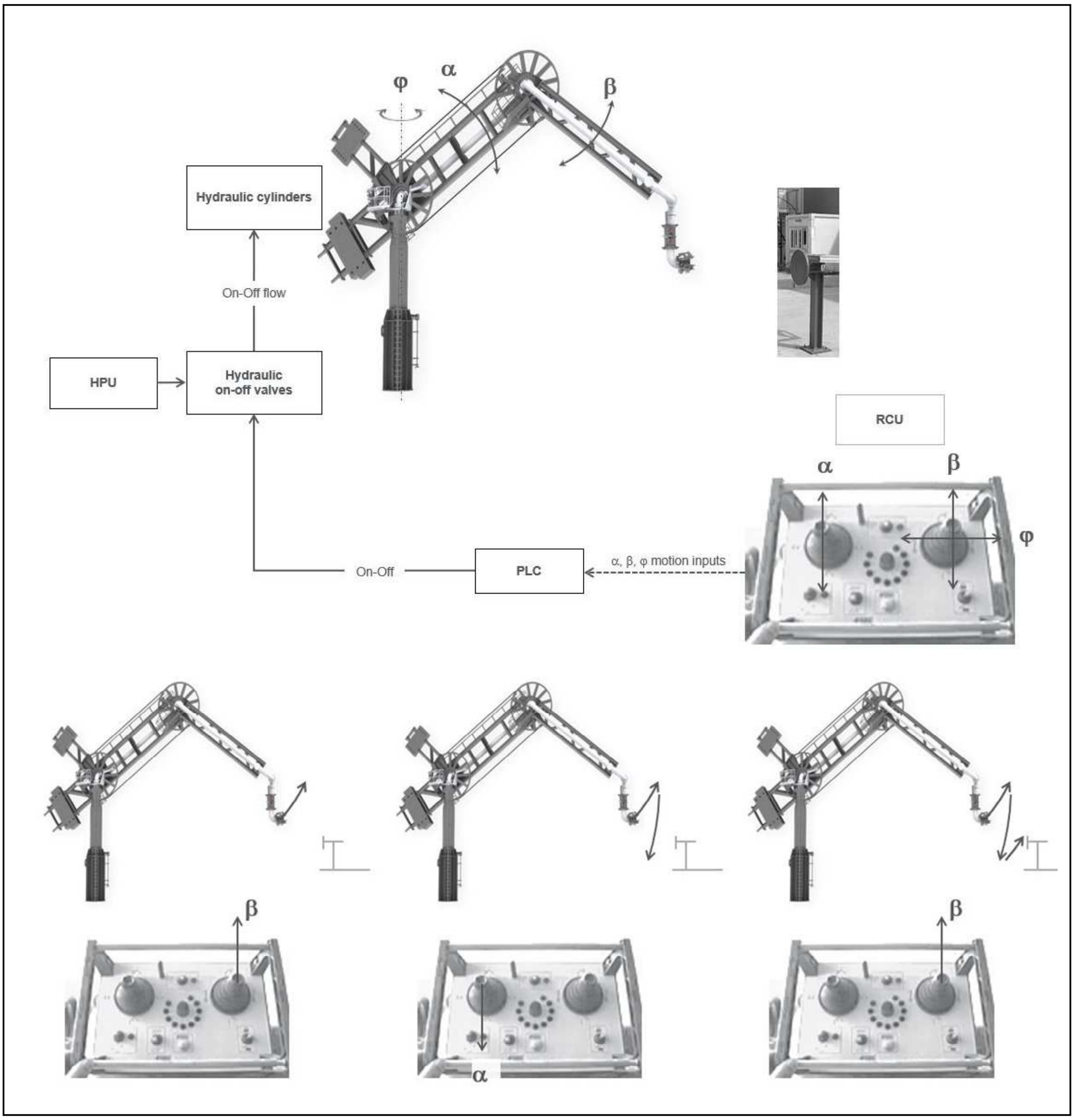

Figure 2: Conventional/articular control mode

Terminals and refineries may face high turnover and come to a situation where operators have no or limited training on loading arms operation, facing equipment damages when operating the loading arms, for instance seals damage due to shocks with the ship flange and/or delay due to long connection/disconnection operations.

Finally, when the ship is subjected to wave induced motions, the connection operations of loading arms installed in an exposed jetty or offshore to the ship may become nearly impossible. T.EN Loading Systems do supply field proven targeting system that enables connection/disconnection operations under significant ship wave induced motions (typically up to 2.5 meters significant wave high), but the required hardware cannot be endorsed for slightly exposed terminals that may experience occasionally some ship (un)loading delays.

2. EASE OPERATIONS THROUGH NEW CONTROL MODES

2.1. Easy Drive mode

Whereas with conventional on-off hydraulic the operator directly commands the MLA rotations – slewing, inboard arm luffing and outboard arm luffing – to indirectly control the MLA connection flange, Easy Drive allows the operator to directly commands the rectilinear motions of the MLA connection flange – right/left, fore/back and up/down – and indirectly acts on the MLA rotations through a controller.

Based on the current MLA position, given by angular sensors measuring the current angle of each MLA rotation (slew, inboard arm and outboard arm), and the targeted rectilinear direction and speed, the controller calculates the required rotary motion of each MLA rotation.

Furthermore, with Easy Drive, the operator can tune the rectilinear speed by pushing more or less on each joystick of the RCU (refer to Figure 3). This allows smooth displacement with virtually no oscillation of the connection flange

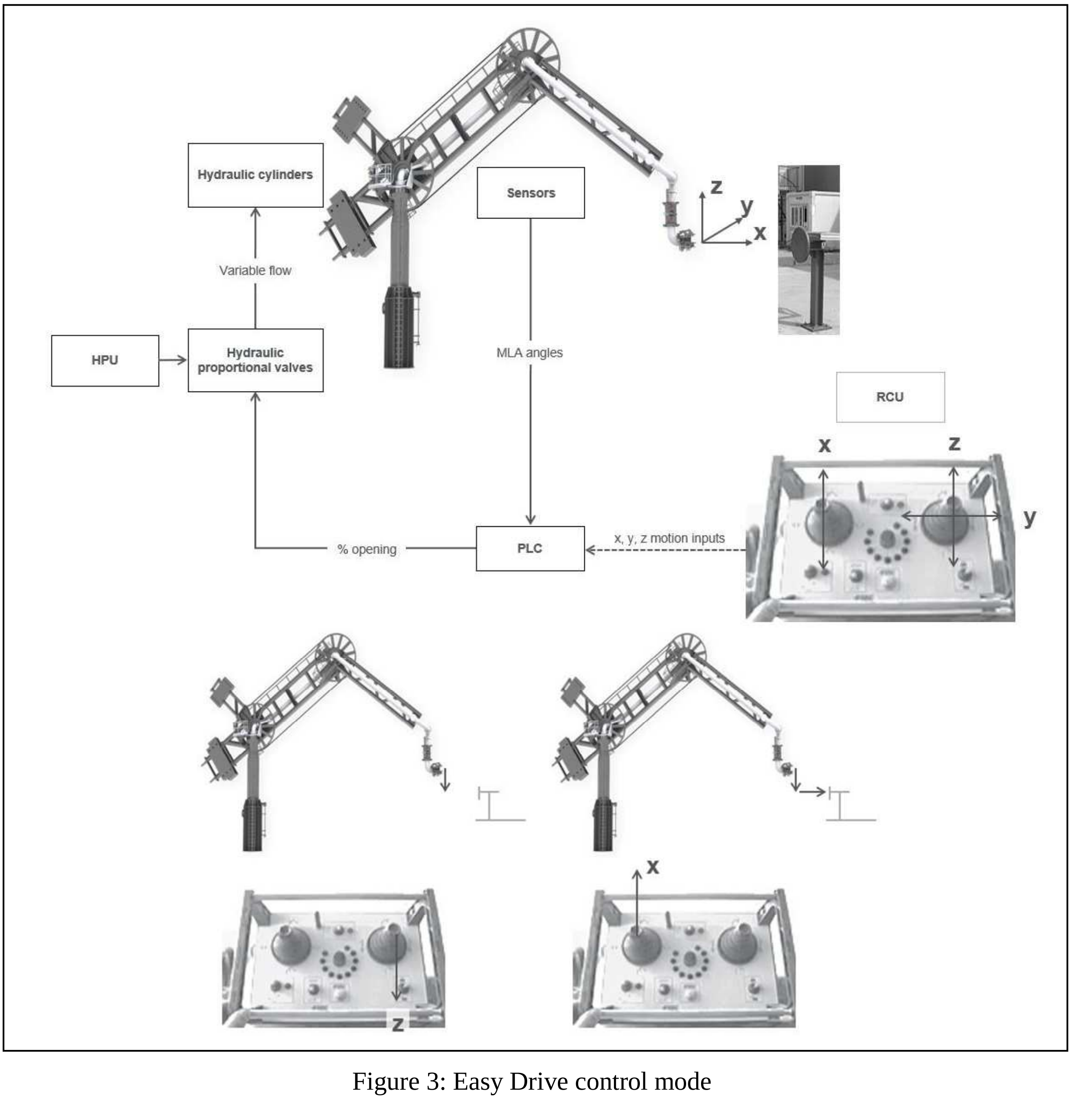

Figure 3: Easy Drive control mode

Compared to the conventional control, Easy Drive requires:

- An MLA fitted with angular sensors to measure the angle of each rotation. Angular sensors are commonly used on MLA as part of the Constant Position Monitoring System (CPMS) that allows the monitoring of the MLA position during the loading operation.
- The use of proportional hydraulic valves instead of on-off valves.

2.2. Auto Drive mode

The ultimate objective is to head towards an unstaffed MLA jetty. In such scenario operator presence on site would no longer be required, but only supervision from a remote location.

The current development conducted by T.EN is the first step toward this goal: one terminal MLA operator shall still be physically present on the ship manifold platform to supervise the operations and intervenes in case of any unexpected event (e.g. ship crew member approaching the operating area of the MLA during its movement). Furthermore, other mandatory operations, e.g. enabling and testing of safety functions, tightness test, etc., still require on a short-term manual interventions.

The level of automation currently proposed by T.EN already enables to lower down drastically the level of human intervention that is normally required to connect/disconnect the MLA, by integration of automatic and seamless connection/disconnection sequences. The following benefits were identified:

- Reduction of human exposure and improvement of operation safety.
- Reduction of operator training requirements.
- Reduction of manning requirements.
- Shortening of operations duration.
- Risk reduction of material damage due to incorrect operation.

The frame of development of the Auto Drive mode of operation is as follows:

- Operation in sheltered areas.
- Automation of the following operation steps:
    - Unparking.
    - Manoeuvring to ship manifold.
    - Connection to ship manifold.
    - Disconnection from ship manifold.
    - MLA retraction to parking position.
    - Parking.

Architecture of the Auto Drive control is schematised Figure 4:

- The operator’s eyes are replaced by a vision system specifically designed to assess the pose of the ship manifold with respect to the MLA coupler. It is the result of an in-house development to fit the application purpose and is based on available hardware and software components.
- The operator’s experience is supplemented by a software embedded in the Program Logic Controller (PLC), generating MLA trajectories based on the vision system captions and position sensors.
- The operator authorizes the automatic sequence to proceed using a joystick tilted one side or the other to respectively run to connected position or run to parked position. When the operator stops tilting the joystick, the MLA stops in the current position (i.e. dead-man control philosophy).

- At any time, the operator can switch from automatic to manual mode and vice-versa. The operating status of the MLA (manual mode or automatic mode) is reported by a beacon located at the top of each base riser and visible by the operator from the ship manifold platform.

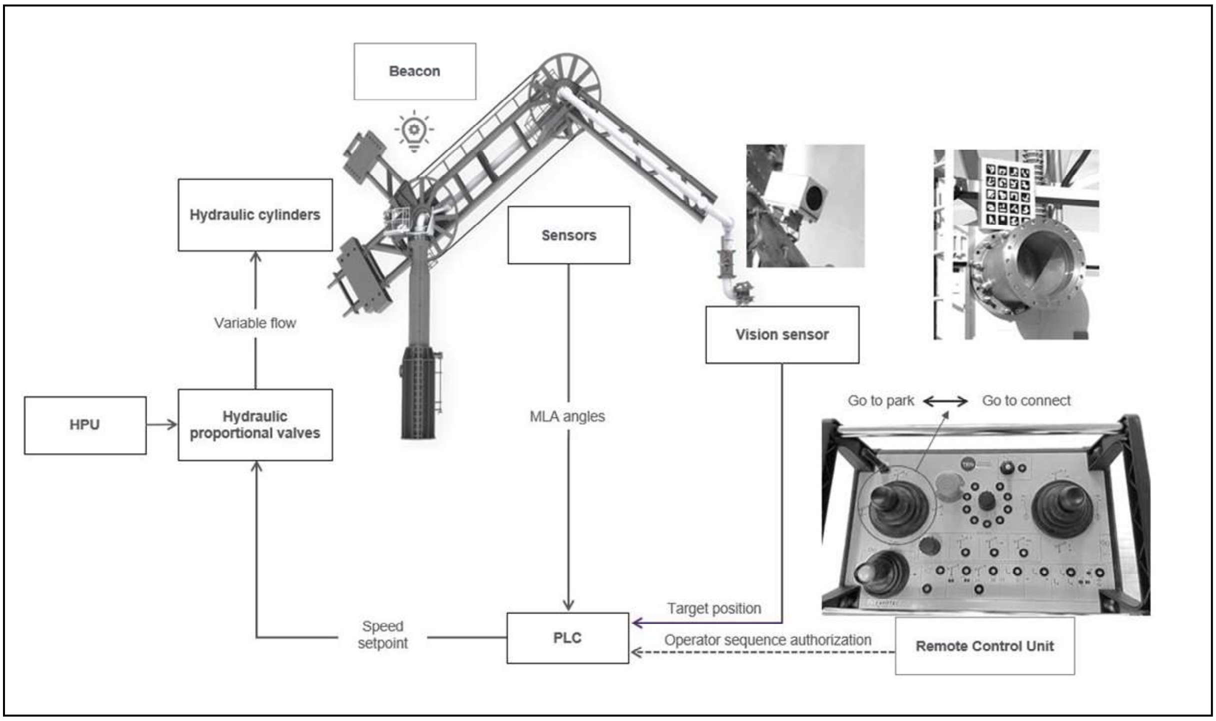

Figure 4: Auto Drive control mode

3. EASE MAINTENANCE THROUGH DATALOGGING AND PROCESSING

As of today, the conventional maintenance strategy for MLA is calendar/time based preventive maintenance: the maintenance activities are performed on regular intervals usually based on manufacturer recommendations, and those from its sub-suppliers.

Such approach does not capture the specific conditions and frequency of use of the asset. It can either lead to premature part replacement or repair; or in worst case scenarios, to late interventions on equipment for which potential irremediable damages may occurred. As a conservative measure, the maintenance frequencies are usually increased, leading to systematic and condensed maintenance schedules leading to high operating costs and jetty unavailability.

The usage-based preventive maintenance is learning from the actual utilization of the equipment within the site-specific conditions. The manufacturer provides customized maintenance recommendations and offer a tailor maintenance program to the users. This approach implies collection and interpretation of data emanating from the equipment.

T.EN has developed a datalogging architecture that post treat raw data raising from the field and transform it into valuable information to users. The main objectives of this new service are to:

- Customize the maintenance schedule,
- Assist the operation team to take informed decision such as the anticipation of its maintenance activities,
- Detect and alert the operation team on any abnormal arm behaviour.

Via an online dashboard designed by T.EN, the user can visualise the status of his loading arm bank (Figure 5).

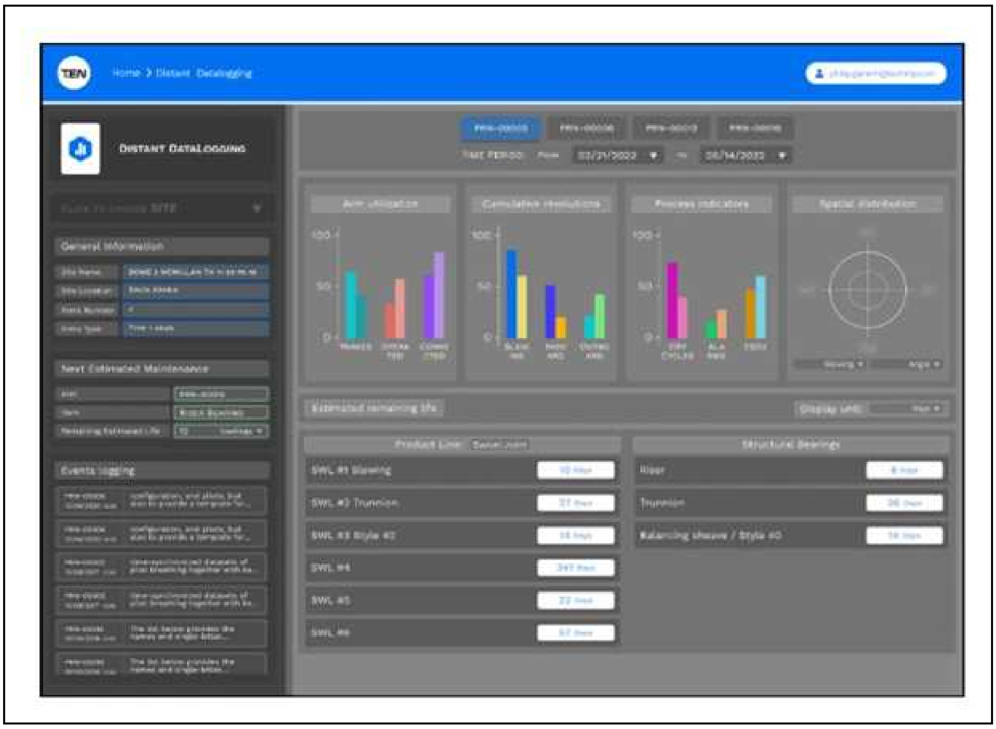

Figure 5: T.EN LS online monitoring & maintenance dashboard

A particular focus has been made on taking the cybersecurity level to the highest standards throughout the data process.

The next step will be to gradually move to predictive maintenance for key MLA components, such as structural bearings. Based on historical data, live data from sensors and contextual data specific to a site, it would be possible to model equipment behaviour, establish maintenance predictions and provide more insights to the operation team.

4. GO TO ELECTRIC DRIVES

Above improvements to conventional hydraulic MLA have lead T.EN LS to consider the use of electrical drives instead of hydraulic drives. Indeed, electrical drives offer great position control allowing, more easily than with hydraulic drives, the automation of the MLA operations. Furthermore, electric drives include, without additional hardware, permanent monitoring devices of speed, position, manoeuvring torques, etc. and offer extensive monitoring and diagnosis features.

There are no fundamental functional differences between the e-MLA and the hydraulic MLA (h-MLA). Both the e-MLA and the h-MLA rely on the same proven mechanical architectures and technologies of articulated piping assemblies.

The core functions of the MLA, i.e. the pressure line carrying the transferred product and the structure, are scrupulously identical in both versions. The e-MLA differs from the h-MLA only in that electrical gearmotors are used as prime movers instead of hydraulic cylinders and/or motors as shown Figure 6.

All e-actuators for the MLA manoeuvring consist of an electric gearmotor acting on pinion/wheel transmission.

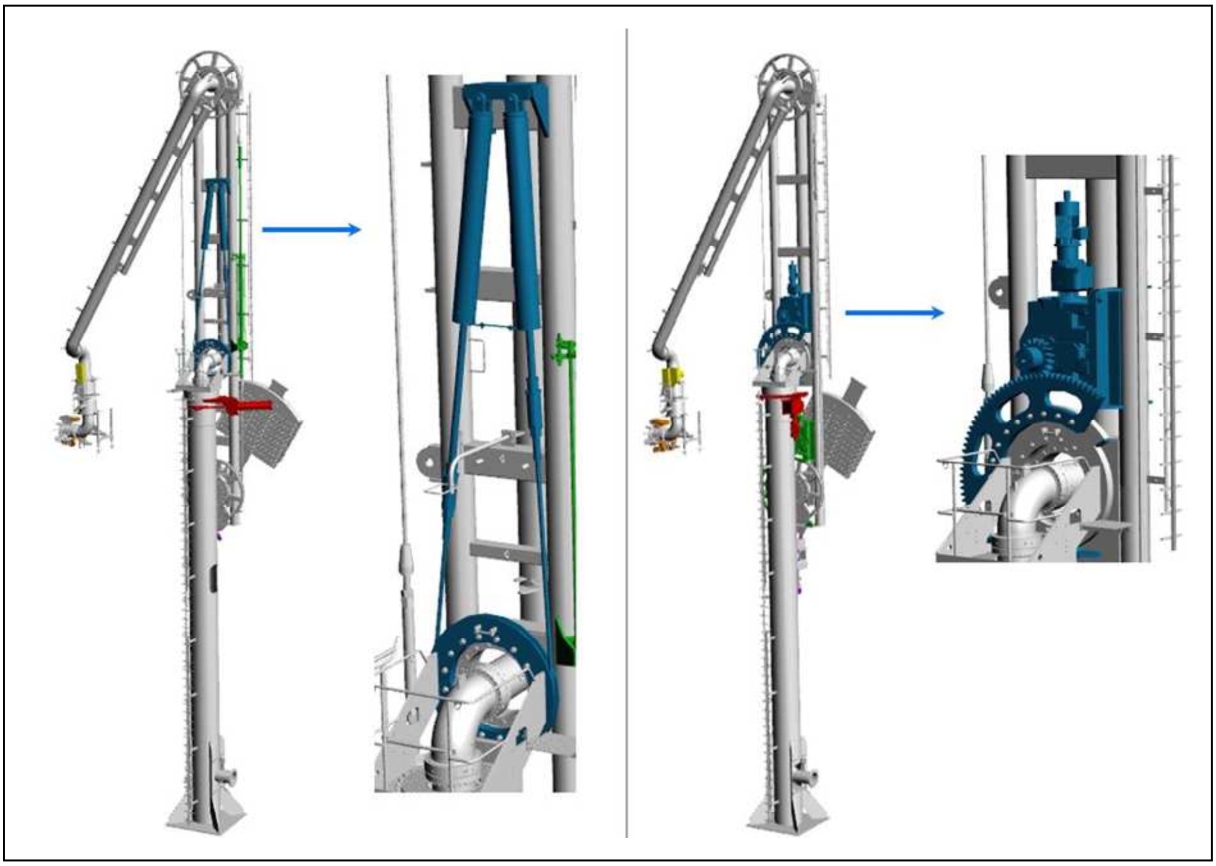

Figure 6: Typical 16” LNG MLA h-MLA version (left) and e-MLA version (right)

When connected to the ship at the manifold, the MLA shall follow her motions to avoid overstressing the MLA structure, the product line and ultimately the ship manifold structure. On a h-MLA, a hydraulic “freewheeling” solenoid valve is de-energized as soon as the MLA is connected to the ship manifold and allows the hydraulic oil to freely circulate between the chambers of each cylinder (namely inboard arm luffing, outboard arm luffing and slewing). The freewheeling requirement for the electric gearmotors of the MLA manoeuvring has been identified as a critical novelty requiring qualification activities.

Manoeuvring e-actuators have been qualified on a dedicated test bench designed to simulate all MLA manoeuvring operations:

- Manoeuvring in normal conditions (MLA balanced) and emergency conditions (MLA unbalanced after emergency release), where the gearmotor is energized and drive the MLA.
- Freewheeling (MLA connected to the ship manifold), where the gearmotor is de-energized and is back-driven.

The test bench consists of a rack able to be driven in translation either by a hydraulic cylinder or by the gearmotor to be tested through the pinion mounted on its output shaft (refer to Figure 7). The pinion/rack mechanism mimics the e-manoeuvre pinion/wheel mechanism.

To simulate the manoeuvring of the MLA, the gearmotor is energized and control the speed of the rack. The hydraulic cylinder is controlled to apply a reaction load corresponding to the MLA friction, inertia and unbalancing.

To simulate the freewheeling of the MLA, the gearmotor is de-energized. The rack speed is controlled by the hydraulic cylinder. The back-drive load of the gearmotor is measured thanks to a load sensor on the rack.

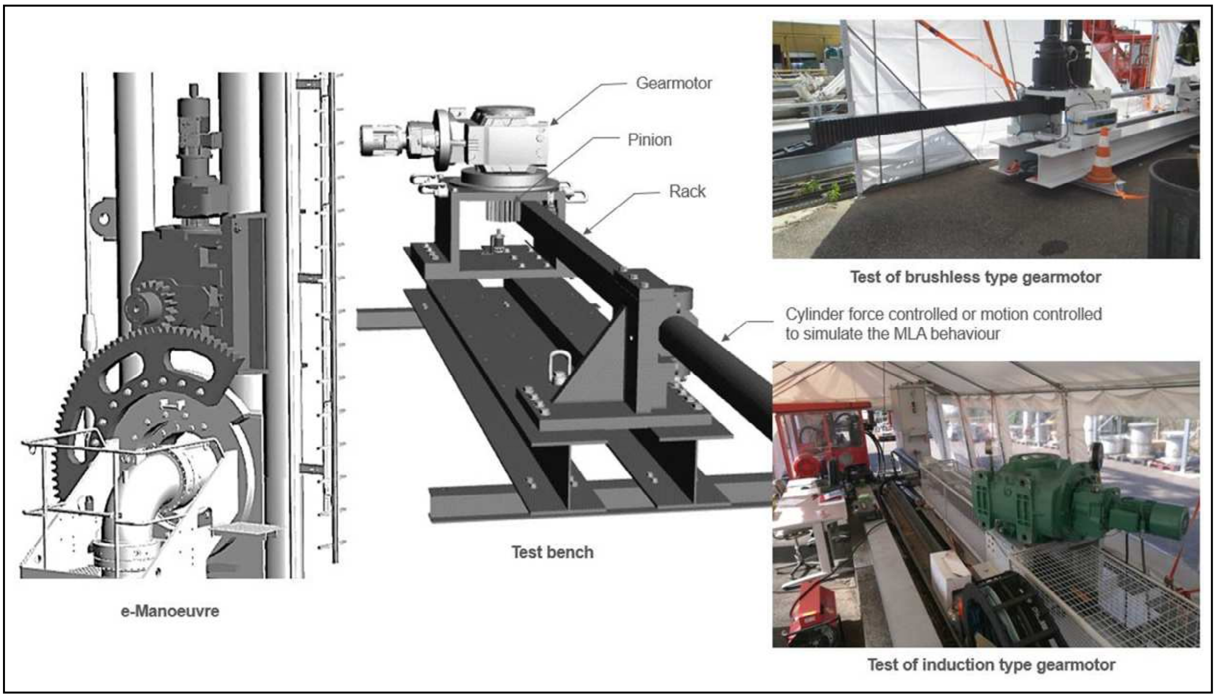

Figure 7: e-Manoeuvre tests

Back-drive loads of the gearmotor have been measured at several speeds to capture the damping of the gearbox. Ambient temperature has been identified as one key influential parameter. Hence a climatic chamber has been built around the gearmotor to lower down the ambient temperature up to -30 °C and capture the impact of the gearbox lubrication oil viscosity increase with the decrease of the temperature. Based on measured back-drive loads, freewheeling capability of the e-MLA has been confirmed by time domain Finite Element Analysis (Figure 8).

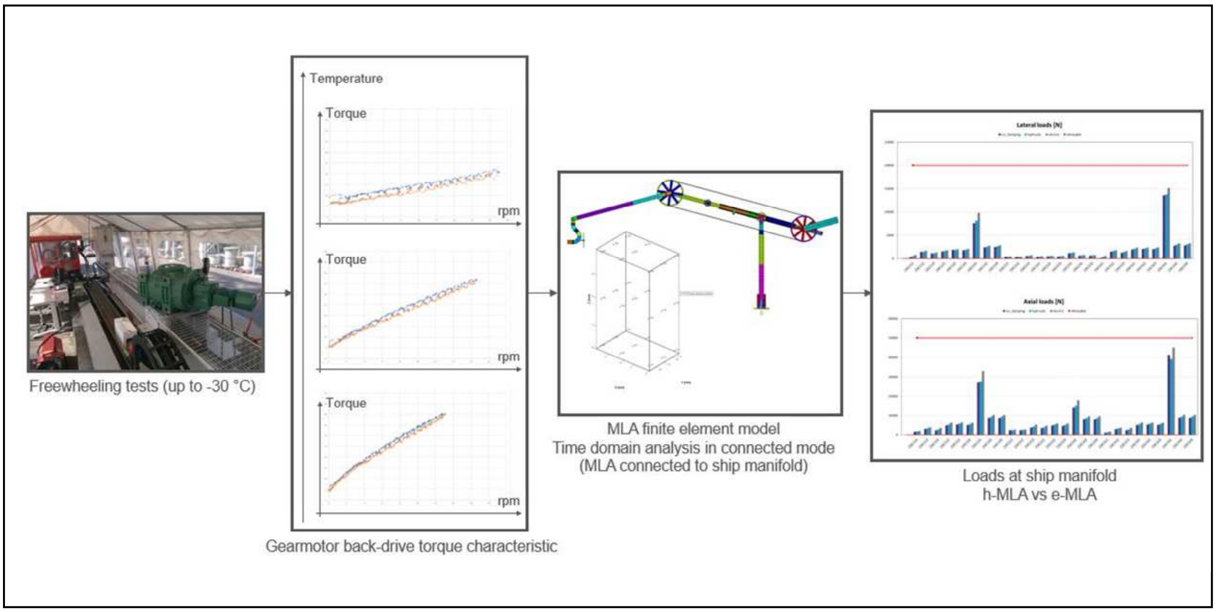

Figure 8: Gearmotor freewheeling ability verification process

The h-MLA requires equipment to convert the electrical supply into hydraulic power (HPU skid) and to store the hydraulic energy (accumulator skid). While the hydraulic is supplied to each h-MLA trough a selector valve assembly, the e-MLA package has a simpler layout with one unique cabinet comprising the motor variable frequency drives. This is replacing the several hydraulic skids hydraulically interconnected (Figure 9).

The complex and spread hydraulic tubing as well as hydraulic cylinders, inherent to hydraulic drives, are eliminated and replaced by cables and off-the-shelf components, easy to integrate on the jetty, and simple to maintain in condition.

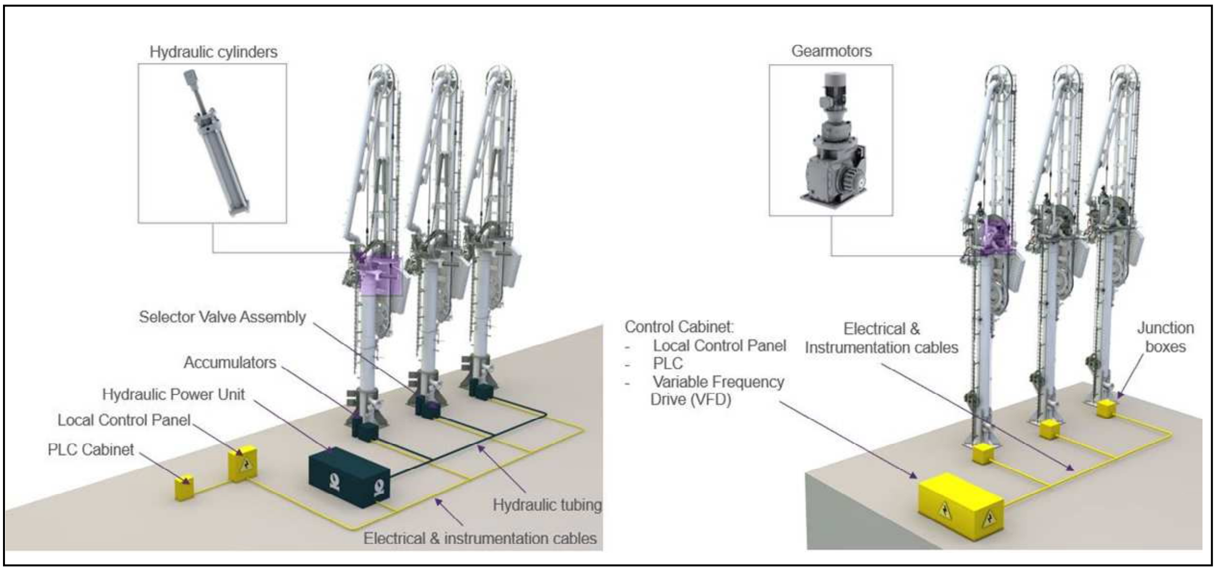

Figure 9: Typical arrangement of a bank of h-MLA (left) and e-MLA (right)

A hydraulic system implies to establish a recurring maintenance scheme (e.g. leak checks, replacement of filters and seals, etc.). This labour-intensive activity requires as well the management of spare parts, to ensure the MLA integrity over its lifecycle. As an example, the h-MLA is fitted with hydraulic flexible hoses at each swivel assembly. One MLA comprises almost 30 flexible hoses which need to be replaced each 5 years. In the end, the downtime per MLA for the replacement of the flexible hoses is typically 5 to 7 days including the duration to erect and remove the scaffolding. Furthermore, maintenance of the hydraulic lines presents a high risk of oil release to the environment. Elimination of all the hydraulic tubing is one of the biggest benefits to switch to electrical drives: electrical components, electrical motors, drives, cables, require very limited or no maintenance.

The e-MLA brings significant advantages compared to the h-MLA from a reliability and availability perspective by drastically reducing the maintenance workload and the associated downtime and OPEX. In addition, electrical drives offer extensive control and monitoring capabilities without additional hardware, opening the door to automatization of operations (Auto Drive) and predictive maintenance.

5. CONCLUSION

With eased operations, thanks to the Auto Drive, and eased maintenance activities, through the monitoring features, combined with electrified actuators which amplify the benefits of these new functions, T.EN Loading Systems aims at entering a new area for MLA.

On a short-term basis, T.EN Loading Systems is currently assembling a demonstrator of its innovative LNG jetty design, including five (5) e-MLA. One of the MLA and associated jetty control system will at full-scale physically in our testing courtyard and the four (4) others will be as digital twin accounting for the jetty context. This full-scale demonstrator will confirm the benefits of the new generation of MLA, and T.EN readiness to engineer and manufacture such innovative product.

We believe this will be a fundamental step for the industry to embrace this electrification as a mature technology and as an enabler to automation and towards unstaffed jetty operations.