APPLICATION OF LINELESS TECHNOLOGY IN AUTOMATIC MOORING USING VACUUM SYSTEM

Adhitya Rahman Kuscahyo[1*], I G. N. Sumanta Buana[1]

[1] Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: 6021221006@mhs.its.co.id

Received: January 1, 2024 | **Accepted:** February 1, 2024 | **Published:** February 2, 2023

DOI: 10.12962/j27745449.v4i3.xxx | **Issue:** Volume 4 Number 3 2023 | **E-ISSN:** 2774-5449

ABSTRACT

The paper explores the innovative application of lineless technology in automatic mooring systems through the utilization of vacuum systems. Departing from traditional mooring methods, this approach offers enhanced safety, efficiency, and environmental sustainability. The study provides a concise overview of vacuum-based lineless technology's integration in automatic mooring, emphasizing its unique advantages and potential challenges. Vacuum-based lineless mooring systems employ advanced suction mechanisms, sensors, and control algorithms to achieve secure vessel mooring without manual intervention. This novel approach significantly reduces operational risks, minimizes wear and tear, and optimizes berthing precision. The paper delves into the technical intricacies of sensor integration, real-time monitoring, and adaptive controls, ensuring reliable and safe mooring even under dynamic environmental conditions. The adoption of vacuum-based lineless technology introduces considerations like technological reliability, cyber-physical security, vessel adaptability, and port infrastructure compatibility. Through a blend of literature review and practical insights, the paper evaluates the feasibility and economic implications of this approach, highlighting its potential to revolutionize maritime practices. As the maritime industry seeks forward-looking solutions, vacuum-based lineless mooring technology emerges as a promising avenue for reshaping vessel berthing and contributing to sustainable port evolution.

Keyword: Lineless technology, Automatic Mooring, Vacuum Systems

Introduction

Maritime transport is vital to the global economy. Port and maritime operations require ship mooring. Ships have long used line-based mooring. High risks, fuel consumption, equipment and ship damage, and environmental damage result from this method. Container loading and unloading require port moorings. This process needs careful handling and a visible system for best results. What happens next depends on the mooring process's design and mechanics. [1]. Line-based mooring—tying ships down with ropes—has been the standard for shipping companies for decades [2]. This global docking method secures ships to docks or buoys with ropes or chains during loading, unloading, and other activities. This method has worked in the maritime industry for years, but stakeholders are realizing its limitations. Risks and issues surround rope-based ship mooring. These risks include ship and equipment damage from friction and pressure during docking and departure, increased fuel consumption from ship engines' tension to maintain position, and air pollution and noise from high-RPM ship engines during mooring. Maritime companies are addressing inefficient and dangerous rope-based ship mooring to improve safety, efficiency, and sustainability [3].

A total of 25 maritime incidents and 14 severe maritime incidents were reported. These casualties resulted from mooring lines buckling or becoming trapped and crew members tripping, slipping, falling, being struck, or colliding during mooring operations. This resulted in a total of 27 injuries and 13 severe injuries. According to a report by CHIRP Maritime, there were 10, 12, 8, and 13 mooring accidents in 2018, 2019, 2020, and 2021, respectively. From 2019 to 2021, MACI reported mooring operation accidents and incidents at 7.14%, 5.26%, and 14.55% [4].

A vacuum secures the ship to the dock or buoy in lineless technology, a novel approach. Using advanced vacuum mechanisms, smart sensors, and intelligent control algorithms, vessels can moor without human intervention. This approach may reduce operational risks, ship and equipment damage, and mooring accuracy. Since ship engines can run at lower RPMs during mooring, vacuum-based ropeless technology may reduce environmental impact.

Automatic mooring system and its benefits

Based on research conducted by Kuzu and Arslan in 2019, it was revealed that the vacuum mooring system offers several significant advantages despite requiring a higher initial cost than conventional mooring systems [4]. It can save money in the long run due to lower operational costs. This system eliminates conventional mooring rope injuries, improving safety. In dock fires or explosions, the system's fast ship attachment and release is crucial. Due to reduced ship propulsion and tugboat operations, the vacuum mooring system reduces port emissions. Due to its efficiency, safety, and reduced environmental impact, the vacuum mooring system is appealing to the maritime industry despite its higher initial investment.

Potential for improvement and sustainability

Automatic mooring systems with renewable energy may improve sustainability. Technology, energy efficiency, cost-effectiveness, environmental impact, and carbon emissions reduction are examples.

Automatic Mooring Systems (AMS) have been shown to reduce carbon emissions significantly. For instance, a study found that using an AMS could reduce carbon emissions at seaports by about 76.78% [5]. Another study found that introducing automated mooring systems could significantly reduce CO2 emissions (up to 77%, based on the case study) [6].

The integration of renewable energy sources with automatic mooring systems can lead to increased energy efficiency. For example, integrating Wave Energy Converters (WECs) into port breakwaters can lead to the efficient use of space Fields [6]. Moreover, using lightweight, integrated photovoltaic (PV) systems can enable reduced mooring costs and faster installation for floating devices.

Automatic mooring systems are expensive, but using renewable energy can reduce their costs. The mooring system can account for 20–30% of wave energy converter construction costs. However, renewable energy can lower these costs. For example, a study found that the cost of the mooring system was successfully reduced by more than 49.2% through the optimization of mooring system designs [7].

Marine Renewable Energy (MRE) harnesses energy from the ocean and provides a low-carbon, sustainable energy source for national grids and remote uses [8]. Integrating MRE with automatic mooring systems can have a positive environmental impact. However, potential ecological effects of marine renewable energy development, such as collision risk with turbine blades and impact on marine life, must be considered and mitigated [8].

Successfully integrating automatic mooring systems with renewable energy requires technological advances. New inverter technology using silicon carbide transistors and high-frequency planar magnetics can reduce grid-tied inverter cost and size. Creating self-extinguishing PV connectors can also prevent PV system fires.

Impact on the maritime industry

A better understanding of vacuum-based ropeless technology in automatic mooring systems is needed to inform the maritime community and related industries. We will also evaluate the economic impact of this technology, which could transform maritime practices and make ports more sustainable. Thus, these efforts should help meet the maritime industry's increasingly complex and sustainable needs.

Methodology

Vacuum-based lineless mooring systems

In 2014, Cavotec pioneered the development of the initial automated ship-to-ship docking system (depicted in Figure 1). This innovation facilitated container exchanges between two ships at sea. The core components of this system include vacuum pads, robotic arms, cables, automated winches, and ship fenders [9]. This groundbreaking system streamlines container transfers between vessels, reducing human intervention and elevating safety and operational effectiveness on the sea.

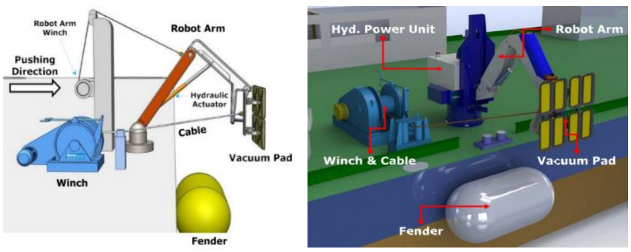

Figure 1. Design automated ship-to-sip; Hardware and arrangement automated mooring system.

The automated vacuum mooring system comprises several key elements: 1. the vacuum suction pad,

2. the mechanical linking device, 3. the transmission mechanism, and 4. the control system. This configuration is depicted in Figures 2 and 3. The fundamental principle of the vacuum suction pad involves extracting air from the pad using a vacuum pump, generating negative air pressure within it, thus causing the object to be securely attached. The vacuum suction pad makes direct contact with the vessel's hull, sealing its edges with rubber, and it is linked to the vacuum pump equipment through a nozzle.

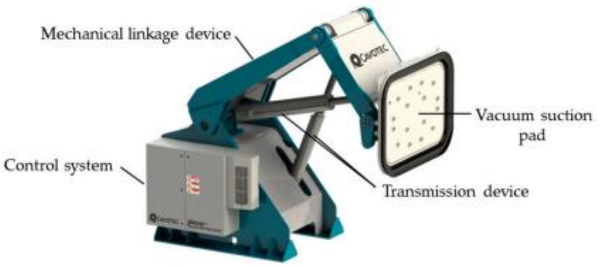

Figure. 1 The components of a vacuum-based lineless mooring system with two transmission devices and a single pad.

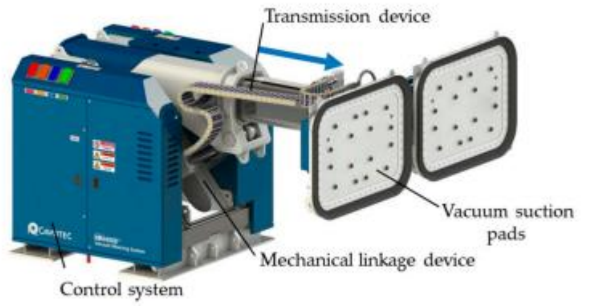

Figure. 2 Illustrates the vacuum-based lineless mooring system's components, consisting of one transmission device and two pads.

The vacuum-based lineless mooring system secures ships in a novel way. The vacuum-based lineless mooring system activates its vacuum pump as the ship approaches the dock, usually within a few meters. The vacuum pad gently pulls the ship to the dock until mooring. The vacuum pad suctions the ship during mooring. The vacuum-based lineless mooring system's safety system maintains suction force between the ship and the system after mooring. Even in the event of a power failure, the vacuum-based lineless mooring system can maintain the suction power for up to 2 hours [10]. Additionally, the system can dynamically adjust the ship's position in real-time to compensate for any vessel movement. Sensors are integrated into both the vacuum pad and the hydraulic system to provide crucial data to the system. These sensors monitor parameters such as the vacuum percentage and the suction force applied to the ship (measured by sensors within the vacuum pad) as well as the ship's motion information (sensed by the hydraulic system). All of this data is presented and monitored via a computer interface.

These sensors meticulously monitor a range of parameters, including the vacuum percentage and the precise suction force applied to the ship, which are measured by sensors embedded within the vacuum pad. Additionally, the sensors in the hydraulic system capture the ship's motion information. All of this invaluable data is collected, processed, and presented through a user-friendly computer interface, allowing for comprehensive monitoring and control of the entire vacuum-based lineless mooring system.

The integration of automatic mooring systems with renewable energy sources

The technical integration involves the physical connection of the automatic mooring system with the renewable energy source. This could involve installing renewable energy generation systems, such as solar panels or wind turbines, at the port or on the mooring system itself. The generated energy can then be used to power the automatic mooring system. For instance, the vacuum-based lineless mooring system consists of four main elements: the vacuum suction pad, the mechanical linking device, the transmission mechanism, and the control system. The vacuum suction pad makes direct contact with the vessel's hull, sealing its edges with rubber, and it is linked to the vacuum pump equipment through a nozzle. The vacuum pump is activated as the ship approaches the dock, drawing the ship towards the dock until the mooring process is completed. In the context of renewable energy integration, renewable energy sources could power the vacuum pump and other mooring system components. For example, solar panels could be installed at the port to generate electricity, which is then used to power the vacuum pump and other mooring system components.

Operational integration involves the processes and procedures that need to be in place to ensure the smooth operation of the integrated system. This could involve developing new operating procedures to account for the use of renewable energy, training for staff on the new systems, and implementing monitoring and maintenance procedures to ensure the ongoing performance of the integrated system. For instance, the vacuum-based lineless mooring system's operation involves activating the vacuum pump as the ship approaches the dock, drawing the ship towards the dock until the mooring process is completed. With the integration of renewable energy sources, new operational procedures may need to be developed to account for the variability of renewable energy generation. For example, procedures may need to be implemented to manage periods of low renewable energy generation, such as during the night or low wind.

Control system integration involves integrating the control systems of the automatic mooring system and the renewable energy system. This could involve the development of new control algorithms to manage the interaction between the two systems, as well as the implementation of new control hardware and software. For instance, the control system of the vacuum-based lineless mooring system ensures a continuous suction force between the ship and the system itself, even in the event of a power failure. With the integration of renewable energy sources, the control system may need to be updated to manage the variable power output of the renewable energy system. This could involve the development of new control algorithms to manage the interaction between the mooring system and the renewable energy system, as well as implementing new control hardware and software.

Limit and Risk

While Vacuum-based lineless mooring systems have a few limitations, the thickness of the ship's hull can become a concern when a ship needs to be secured to the dock. When the hull thickness is less than 9.8 mm, there is a risk that the ship's hull may deform due to the Vacuum-based lineless mooring system. Additionally, the vacuum pads should not adhere to glass surfaces. The total force exerted by the Vacuum-based lineless mooring system must also be lower than the maximum force applied to the dock fenders. If the total force of the Vacuum-based lineless mooring system exceeds this limit, it can damage or even break the dock fenders. The Vacuum-based lineless mooring system can only move horizontally within a range of about 0.5 m and cannot move vertically [11]. To achieve an 80% vacuum level, a vacuum pad must have a minimum absorption area of 2.5 m^2. Ensuring the vacuum pad is attached to a flat ship's hull is crucial, as failure can reduce or even eliminate vacuum effectiveness. These are some essential considerations to consider when using Vacuum-based lineless mooring systems.

Operational integration refers to the processes and procedures that need to be in place to ensure the smooth operation of the integrated system. This could involve developing new operating procedures to account for the use of renewable energy, training for staff on the new systems, and implementing monitoring and maintenance procedures to ensure the ongoing performance of the integrated system. For instance, the vacuum-based lineless mooring system's operation involves activating the vacuum pump as the ship approaches the dock, drawing the ship towards the dock until the mooring process is completed. With the integration of renewable energy sources, new operational procedures may need to be developed to account for the variability of renewable energy generation. For example, procedures may need to be implemented to manage periods of low renewable energy generation, such as during the night or low wind.

Control system integration involves integrating the control systems of the automatic mooring system and the renewable energy system. This could involve the development of new control algorithms to manage the interaction between the two systems, as well as the implementation of new control hardware and software. For instance, the control system of the vacuum-based lineless mooring system ensures a continuous suction force between the ship and the system itself, even in the event of a power failure. With the integration of renewable energy sources, the control system may need to be updated to manage the variable power output of the renewable energy system. This could involve the development of new control algorithms to manage the interaction between the mooring system and the renewable energy system, as well as implementing new control hardware and software.

However, integrating renewable energy resources into automatic mooring systems using vacuum technology also has limitations and risks. These include the need to manage the variable power output of renewable energy sources, the potential for damage to the dock fenders if the total force of the vacuum-based lineless mooring system exceeds a specific limit, and the need for regular sensor maintenance to prevent failures before each mooring operation.

Result and Discussion

The Vacuum-based lineless mooring system offers several significant advantages. Firstly, this system is compatible with virtually all vessels as its vacuum pad features a modular design allowing attachment to the vessel's hull. Secondly, it significantly expedites the mooring process compared to traditional rope mooring, capable of mooring a ship in less than 30 seconds. Thirdly, it boasts a high level of automation, enhancing operational safety. Operators only need to press a control button to complete the automated mooring operation via the remote control system, eliminating the need for personnel to work in hazardous areas. Fourthly, the system brings economic benefits by saving time during loading and unloading, accelerating ship turnover at ports, and reducing the workload of mooring personnel. Additionally, the automated vacuum mooring system reduces environmental impact by lowering emissions of pollutants, particularly carbon dioxide, thanks to its quicker mooring process. These combined advantages make the automated vacuum mooring system an attractive choice in the maritime industry [11].

In the Vacuum-based lineless mooring system, sensors continuously monitor the vacuum level in the vacuum pad, sending signals to the control system to regulate the hydraulic device for applying the ship's physical force. Sensor maintenance is crucial to prevent failures before each mooring operation. A standard LCD monitor has an operational lifespan of approximately 35,000 hours, necessitating replacement every 3.5 years. The vacuum pads must remain attached to the hull after mooring and hydraulic power unit maintenance is essential to ensure its proper functioning, including cleanliness, fluid quality, and various checks on the hydraulic system [11].

Aside from measuring the ship-to-dock distance, hydraulic system pressure, vacuum cup suction force, and ship motion, these sensors must also gauge ship speed and wind speed [8]. Consequently, determining if these diverse sensors are entirely suitable for the intricate automated port mooring environment presents a formidable challenge. Most vessels rely on internal combustion engines for power, making automated berthing challenging for some ships that cannot execute sharp turns or agile maneuvers toward the dock. Equipping ships with multiple propulsion systems, such as directional or thrusters, and their main propulsion system may offer a viable solution. Furthermore, in actual mooring scenarios, ship motion is highly complex, influenced by various external factors such as wind, waves, currents, tides, ballast, deballast, and cargo loads. Consequently, the movement mechanism of the Vacuum-based lineless mooring system needs refinement to adapt to the intricate ship-berthing movements. Additionally, the system encounters several challenges, including high initial costs, maintenance complexities exceeding traditional iron bollards, and structural strength requirements necessitated to match each vessel's unique characteristics. The findings indicate that, when taking into account the extent of vessel movement in surge and sway, the ability of a ship to berth using an automated vacuum mooring system is elevated from 65% to 95% [12].

Conclusion

Integrating renewable energy sources into the shipping and transport industry necessitates a comprehensive overhaul of operational procedures and control systems. Operational integration involves the development of new procedures that account for the variability of renewable energy generation, such as during periods of low wind or at night. This could involve training staff on new systems, implementing monitoring and maintenance procedures, and developing new operating procedures. For instance, a vacuum-based lineless mooring system may need to adapt its procedures to accommodate renewable energy sources.

Control system integration requires updates to the control systems of the automatic mooring system. This could involve the development of new control algorithms to manage the interaction between the mooring system and the renewable energy system, as well as implementing new control hardware and software. The control system must ensure a continuous suction force between the ship and the system, even during a power failure.

However, the integration of renewable energy sources into the shipping and transport industry is not without its limits and risks. For instance, the vacuum-based lineless mooring system has limitations related to the thickness of the ship's hull, the type of surface the vacuum pads adhere to, and the total force exerted by the system. These limitations could damage the ship or the dock fenders if not adequately managed.

In conclusion, integrating renewable energy sources into the shipping and transport industry, particularly in the context of vacuum-based lineless mooring systems, is a complex process involving significant changes to operational and control systems. Despite the potential benefits, it also has specific limits and risks that must be carefully managed.

References

[1] D.J. Najoan, D.A. R. Putri, and S. Nurhayati: Produktivitas bongkar muat dan waktu sandar kapal pelabuhan tanjung emas. **4**(1) (2017).

[2] A.P. Putra, M. K. Sitompul, T. Mardalena, and Romadani, Analisis keterkaitan transportasi laut dengan pelabuhan kargo teluk dalam untuk menunjang kegiatan perekonomian masyarakat penyalai Kecamatan Kuala Kampar Provinsi Riau, *J. Jalasena*. **3**(2) (2022) 57–71. DOI: 10.51742/jalasena.v3i2.544.

[3] E. Setiawan, W. Tambunan, and D.K.R. Kuncoro, Analisis Risiko Keselamatan dan Kesehatan Kerja Menggunakan Metode Hazard Analysis (2019).

[4] A.C. Kuzu, Ö. Arslan, and V. Dean, Analytical Comparison of Different Mooring Systems.

[5] A. Ortega Piris, E. Díaz-Ruiz-Navamuel, C. A. Pérez-Labajos, and J. Oria Chaveli, Reduction of CO 2 emissions with automatic mooring systems. The case of the port of Santander, *Atmospheric Pollut. Res.* **9**(1) (2018) 76–83. DOI: 10.1016/j.apr.2017.07.002.

[6] D. Clemente, T. Cabral, P. Rosa-Santos, and F. Taveira-Pinto, Blue seaports: The smart, sustainable and electrified ports of the future, *Smart Cities*. **6**(3) (2023) 1560–1588. DOI: 10.3390/smartcities6030074.

[7] H. Park and S. Jung, Design and automated optimization of an internal turret mooring system in the frequency and time domain, *J. Mar. Sci. Eng.* **9(**6) (2021) 581. DOI: 10.3390/jmse9060581.

[8] A.E. Copping et al., Potential environmental effects of marine renewable energy development—The state of the science, *J. Mar. Sci. Eng.* 8(11) (2020) 879. DOI: 10.3390/jmse8110879.

[9] Y.Y. Kim, K.-J. Choi, H. Chung, S. Han, and P.-S. Lee: A ship-to-ship automatic docking system for ocean cargo transfer, *J. Mar. Sci. Technol*. **19**(4) (2014) 360–375. DOI: 10.1007/s00773-014-0256-3.

[10] "Automated Mooring," Cavotec SA. Available from: https://www.cavotec.com/en/your-applications/ports-maritime/automated-mooring Accessed at 14 October 2023

[11] E. Díaz-Ruiz-Navamuel, A. Ortega Piris, A.-I. López-Diaz, M. A. Gutiérrez, M. A. Roiz, and J. M. O. Chaveli, Influence of ships docking system in the reduction of CO2 emissions in container ports, *Sustainability*. 13(9) (2021) 5051. DOI: 10.3390/su13095051.