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Logistics

Logistics is the management of how things get from origin to destination, from source to use. The scope of logistics also includes getting the planet to a better place sustainably by making improvements in system visibility, flexibility, and productivity. So, it’s no longer just about how we get things to where we want them; it’s also about how we survive.
Share your thoughts with abb.review@ch.abb.com .

EDITORIAL

Logistics

Dear Reader,

There is always an element of satisfaction at the completion of a project, be it a car rolling off the end of a production line, or a process plant starting up for the first time. Much of the credit, however, goes to the activities in the background that bring together the materials, parts, tools, skills and data.

Scheduling relies on accurate data. Operators need to know what resources are available at any moment and how quickly they can be replenished. Managers need to know how to source and move resources, and reduce the costs and energy required.

In the following pages we present, among others, a tool that estimates stockpiles using visual analysis, and a software that optimizes the movement of stackers by anticipating oscillations. We look at sensors tackling marine emissions and enabling energy storage, artificial intelligence supporting operator decisions, and a transformation of spare parts management. As you will see, it's an exciting time for logistics.

Enjoy your reading,

Björn Rosengren
Chief Executive Officer, ABB Group

HUBERTUS VON GRÜNBERG

The research award is dedicated in honor of the achievements of Hubertus von Grünberg, who served as ABB Chairman from 2007 to 2015.

Von Grünberg, a theoretical physicist who wrote his doctoral dissertation in 1970 on Albert Einstein's theory of relativity, was instrumental in setting ABB on a path to sustainable growth. His legacy includes his support for research, both at universities and within the company - establishing it as one of ABB's strategic imperatives. Today the group invests some $1.3 billion annually in R&D and operates numerous research centers around the world- underlining ABB's claim to be one of the most innovative companies worldwide in driving the digital transformation of industries.

01

RESEARCH AWARD

Hubertus von Grünberg Award

Calling all talented researchers: The Hubertus von Grünberg award is now open to applications. This prestigious prize is presented only every third year and recognizes outstanding research in the field of automation or electrification. It grants the sum of $300,000 in support of postdoctoral research.

Photo 02: Publik. Agentur für Kommunikation

—
01 Hubertus von Grünberg.

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02 Past laureates of the award.

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You can find more information about the award here: new.abb.com/hvg-award

02

PAST LAUREATES

2019
The 2019 prize was awarded to Ambuj Varshney of Uppsala University, Sweden, in recognition for his work on sustainable Networked Embedded Systems (NES). Varshney developed an ultra-low power and long-range communication system (LoRea) for battery-free sensors that harvest small amounts of energy from the ambient environment. He has demonstrated their ability to communicate over distances of up to a few kilometers while consuming only tens of microwatts.

2016
The 2016 prize was awarded to Jef Beerten from the University of Leuven, Belgium, for research on the modeling and control of DC Grids.

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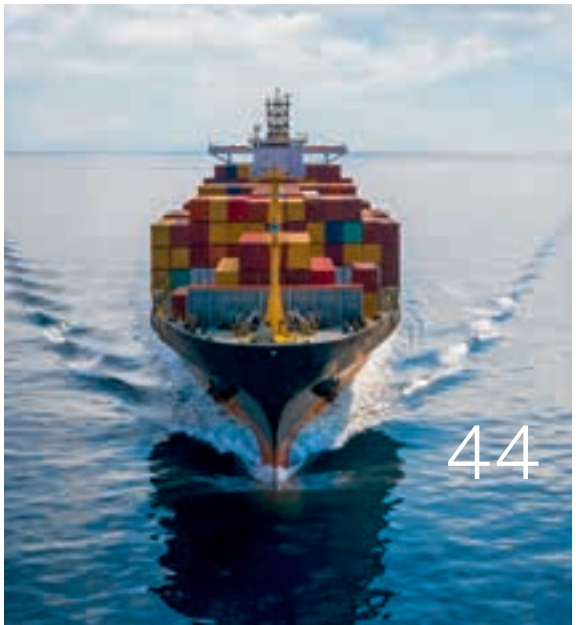
ABB created the research award in honor of its former chairman, Hubertus von Grünberg →01. The prize has been awarded twice so far, in 2016 and 2019 →02.

The award includes a $ 300,000 grant for post-doctoral research and is open to PhD graduates specializing in electrification or automation from any university. The third instalment of the award will be presented in 2022.

The jury consists of professors from leading universities as well as senior ABB researchers and Hubertus von Grünberg himself.

The deadline for submission is 29th January 2022. new.abb.com/hvg-award •

Logistics



Getting new solutions from theory to reliable application can be a thorny logistics challenge. ABB connects customers with the latest research, informed with the right technologies, so that they can see operational improvements repeatedly, profitably, and sustainably.

10 ACOPOS 6D heralds a new era of productivity
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LOGISTICS

ACOPOS 6D heralds a new era of productivity

Conventional industrial production plant is typically set up with a single use case in mind, and is not always easy to adapt. B&R's ACOPOS 6D changes all that with magnetically levitated shuttles that carry parts freely through the production process. ACOPOS 6D is ideal for small-batch production with frequent design and dimension changes.

01

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Today's production machinery takes up a lot of space – but only a fraction of its footprint contributes to the production process directly. Far more real estate is dedicated to carrying products from place to place via conveyor belts, rotary tables, carousels, etc. This seemingly immutable feature of manufacturing has another downside: lack of flexibility. To meet the demands for smaller batches, shorter life cycles and increasing personalization, the shackles of rigidly sequential production – once the mainstay of efficient mass production – must be thrown off. A completely new approach to product transport is needed.

Track systems facilitate dynamic adaption of a process step – but what if the process sequence changes constantly?

More flexible with track systems

New technologies, especially track systems such as SuperTrak and ACOPOStrak [1] from B&R (a company acquired in 2017 by ABB) have made production much more flexible and mass customization economically feasible. Track systems move each product independently and can provide a motion control axis at processing stations. Not only that, but track systems also allow product flows to divide and merge at full speed. By adding multiple instances of slower stations, productivity bottlenecks are removed.

Mass customization

Track systems facilitate the dynamic adaption of a particular process step for a customized part. But what happens if the sequence of steps itself is constantly changing? How can the linear model of product transport be dissolved entirely to create a multidimensional manufacturing space where each product moves independently from station to station without being bound to a rigid, sequential production flow? B&R's ACOPOS 6D provides the solution.

—
01 B&R's modular ACOPOS 6D uses magnetic levitation to bring unprecedented flexibility to manufacturing lines. (B&R is an Austrian automation company that became a business unit of the ABB Group in 2017.)

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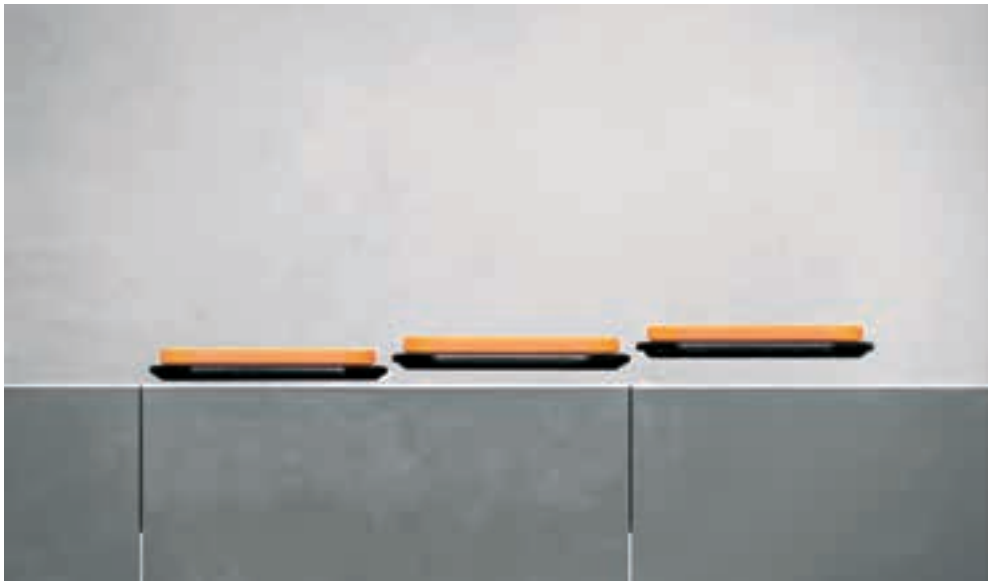
02 Magnetic levitation technology makes it possible to move and manipulate products with six degrees of freedom.



02

03

04

05

ACOPOS 6D: the future of manufacturing
ACOPOS 6D is based on the principle of magnetic levitation: Shuttles with integrated permanent magnets float smoothly and silently over the surface of electromagnetic motor segments, carrying production parts at a height of 0.5 to 4.0 mm →01–02. The modular motor segments measure 240 x 240 mm and can be arranged in any configuration. Ten shuttle sizes carry payloads of 0.6 to 14 kg and accelerate at 20 m/s² up to speeds of 2 m/s. This performance enables ACOPOS 6D to cover a much more extensive range of applications than comparable systems, both in terms of scope and granularity. Shuttles can move freely in two-dimensional space, rotate and tilt along three axes and offer precise control over levitation height. Taken together, that gives the shuttles six degrees of motion control freedom (thus the "6D" in the product name).

ACOPOS 6D has a straightforward construction – there are only three components to work with:
- The 6D controller
- Motor segments
- Shuttles

ACOPOS 6D was developed in cooperation with Planar Motors Inc. (PMI), a company with over 15 years of research and development experience in magnetic levitation technology for industrial manufacturing. PMI (in which ABB is a shareholder) has a rich intellectual property portfolio in the magnetic levitation field. It is intended that PMI will continue to drive research and development and B&R will contribute its know-how in the areas of industrialization, sales and service.

Simple setup and operation
ACOPOS 6D offers nearly limitless possibilities in machine design, yet is remarkably easy to set up.

Unlike comparable systems, each ACOPOS 6D shuttle is assigned a globally unique ID. At startup, the controller immediately knows each shuttle's location on the motor segments, so production can begin without time-consuming homing sequences or manual input by an operator.

A shuttle's location is known to within ±5 µm at all times, making ACOPOS 6D perfectly suited for applications with strict positioning requirements. This positional awareness also allows collision-free paths for each shuttle to be calculated without any additional sensors. Paths are chosen to also minimize energy consumption. ACOPOS 6D also has decentralized intelligence.

ACOPOS 6D uses magnetic levitation to carry production parts smoothly and silently over the surface of motor segments.

All this planning occurs in a dedicated controller – connected to the machine network via POWERLINK (a real-time protocol for standard Ethernet) – which means it has no impact on the performance of the network or machine control system. Other systems use a centralized system architecture, which requires expensive and complex infrastructure that is usually difficult to scale up.

The shuttles can also be used as axes in processing stations – ie, a CNC tool can be mounted rigidly and the shuttle moves the part as required →03.

Space savings
Up to four shuttles can be controlled simultaneously on each ACOPOS 6D segment – a feat unmatched by rival systems and one that delivers a smaller machine footprint and up to four times the processing density. Moreover, tight shuttle formations with no gaps further improve space utilization and enable groups of shuttles to collaborate to carry larger or heavier products.

Since each shuttle can also serve as a high-precision scale (precision: ±1 g), weighing stations can be eliminated, saving further space.

Scalability
Since ACOPOS 6D is modular and decentralized, there are virtually no restrictions on the number of shuttles or segments that can be used on one production line: One ACOPOS 6D Controller can handle up to 200 motor segments and 50 shuttles and multiple ACOPOS 6D Controllers can

03 In a reversal of the normal situation, an ACOPOS 6D shuttle can move a workpiece for precision machining, allowing the CNC tool to be mounted rigidly.

04 The shuttle can also act as a high-precision weigh station.

05 ACOPOS 6D can be synchronized with microsecond accuracy with the B&R vision system and all other B&R components.

be synchronized for larger systems →04. Furthermore, because ACOPOS 6D is fully integrated into the B&R ecosystem, shuttles can be synchronized with servo axes, robots, track systems and machine-vision cameras with microsecond precision →05.

Power and cooling
ACOPOS 6D runs off 48 to 60 V DC, unlike the 110 V AC, or more, required by similar products. Depending on acceleration, speed and payload, shuttle power consumption is about 15 to 50 W.

ACOPOS 6D makes it possible to turn the concept of swarm production into reality.

This energy efficiency often renders active cooling unnecessary. In highly dynamic applications with a large number of shuttles and high rates of acceleration, performance can be increased through active cooling. If needed, motor liquid cooling is easy to implement via the pre-installed piping →06.

ACOPOS 6D in the field
ACOPOS 6D is suited for a wide range of applications, especially where:
- High precision is crucial.
- The order of processing steps varies.
- Items are produced in small batches.

ACOPOS 6D is perfect for processes or environments that are sensitive to contamination – eg, cleanrooms or food and beverage plants – as the magnetic levitation eliminates contact and, thus, abrasion and associated particle shedding. Shuttles and motor segments comply with protection class IP67 as standard. Stainless steel shuttles are also available, and by placing a stainless steel cover over the motor segments, ACOPOS 6D's IP level can be raised to IP69K.

Pilot customers in battery cell production, food and beverage, printing and pharmaceuticals are currently working with ACOPOS 6D. Features such as anti-sloshing algorithms that control acceleration, deceleration and tilt on curves are particularly appreciated.

ACOPOS 6D and track systems like ACOPOStrak and SuperTrak complement each other and will be used together in many applications. ACOPOS 6D implementation is useful wherever one or more of its unique capabilities – eg, six degrees of freedom, high precision or cleanroom suitability – is required. If it is possible to cover an application's requirements with a track system, that is the more economical solution.

Gliding into the future of manufacturing
ACOPOS 6D makes it possible to turn the concept of swarm production into reality. Swarm production is a concept where individual products navigate their own path through the manufacturing system. There is no rigidly preprogrammed sequence of production steps; each product moves independently to just the stations it needs →07. This approach makes it much easier to implement small-batch and mixed-batch production. Different products can be produced on the same machine simultaneously.

The contactless, noiseless, flexible and precise performance of ACOPOS 6D thus heralds a transition from strictly linear production to an open, adaptive manufacturing space – nothing less than a revolution in the way products are manufactured, assembled and packaged.

Pilot applications using ACOPOS 6D are running now and series availability and completion of all certifications are planned for the end of 2021. •

—
06 The segments are equipped with an integrated water cooling system and can be daisy-chained.

—
07 Dissolving the traditional model of linear product transport creates a multidimensional production space.

—
Reference

[1] C. Klingler-Deiseroth, "Intelligent transport for production lines," *ABB Review* 2/2018, pp. 68–73.

06

07

LOGISTICS

Reaching new heights

Working with industry and academic partners, ABB has been able to move beyond theoretical research results to introduce the first limited-version ACS880 drive control program with an anti-pendulum function for stacker crane customers. This new function minimizes mast oscillations and enhances stability, helping customers to reduce material cycling time.

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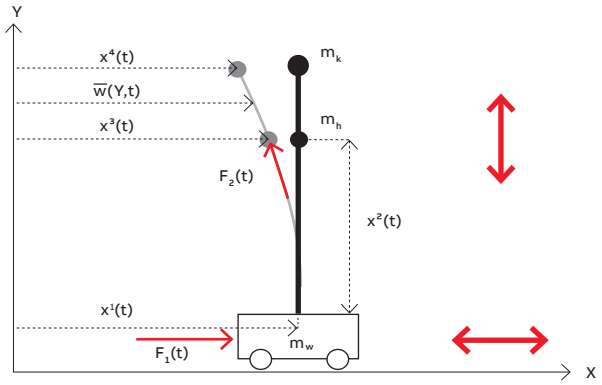
The materials handling industry typically uses stacker cranes to store and retrieve loads. This industry is under increasing pressure to fulfill economic and sustainability targets. Decreased material handling cycle times, demands for reduced costs and energy consumption require the use of ever taller and more lightweight cranes (less metal). These structurally less stiff cranes

Decreased material handling cycle times, etc. require the use of ever taller and more light-weight cranes.

should position loads rapidly and precisely while maintaining workload stability and safety. Yet, such crane frame structures are flexible by nature; crane motion can result in harmful mast oscillations. The inertial force of acceleration or braking movement can reduce stability and derail positioning accuracy; compromising safety and possibly damaging the material being moved. Moreover, the dynamics of these machines



$$pA\ddot{w} = -EI\frac{\partial^4}{\partial Y^4}w,$$

$$m_w\ddot{x}^1 = F_1 - EI\frac{\partial^3}{\partial Y^3}w\Big|_0,$$

$$m_h\ddot{x}^2 = F_2 - m_h g - m_h x^3\frac{\partial}{\partial Y}w\Big|_{x^2},$$

$$m_h\ddot{x}^3 = EI\left(\frac{\partial^3}{\partial Y^3}w\Big|_{x^2_-} - \frac{\partial^3}{\partial Y^3}w\Big|_{x^2_+}\right)$$

01

depends on the lifted load, which varies with the magnitude and position. To circumvent the damaging consequences of oscillations, the crane's operating system requires a few seconds to stabilize so that vibrations can cease before movement can continue. This process is time-consuming and as such reduces throughput and performance.

How then can drive control applications minimize stacker crane mast oscillations while incorporating quick, accurate and robust control at minimal cost, and improve throughput? ABB's answer to this challenge is incorporating an anti-pendulum function option based on ABB's ACS880 Position control program.

A dependable partner

With sustainability and performance paramount, stacker crane manufacturers know they can depend on ABB to provide control strategies to fit their logistical needs and meet environmental and economic goals. ABB introduced ACSM1 motion control drives in 2007. These flexible and versatile drives provide general speed and torque as well as versatile motion control features. Used to control induction, synchronous and asynchronous servo- and high torque motors with various feedback devices, these drives are used by stacker crane customers. Building on innovation, ABB introduced the ACS880 Position control program as a successor to the classic ACSM1 motion control drives for stacker crane customers in 2018 – with absolute and relative positioning, profiled positioning, position synchronizing and fast position latching. Nonetheless, small scale crane manufacturers have yet to develop an anti-pendulum function. Enter ABB to provide these customers with an anti-pendulum solution to minimize mast oscillations, accurately and rapidly.

How it all began and establishing a path

Understanding the important connection between collaboration and innovation to achieve the full potential of their drive control solutions, ABB works closely with their business and academic partners. In early 2017, ABB began a collaborative investigation to determine the feasibility of including an anti-pendulum function and functional safety (and additional base control features) in their ACS880 Position control program for stacker cranes. Having relied on an ACSM1 motion control drive for stacker crane control for over a decade, one of ABB's customers sought a solution to an expanding challenge: achieve higher throughput economically and sustainably in ever taller warehouses, yet avoid mast oscillations in a 68-ton 32 m tall stacker crane that must lift and shift 6-ton loads.

—

Stacker crane manufacturers know that ABB will provide control strategies to fit their logistical needs.

ABB joined forces with the University of Linz, Austria (JKU) to investigate such an

01 A mathematical model of a stacker crane developed by JKU. The forces acting on the crane (F), the mass of the lifting unit m_h, the mass of the tip m_k (used in JKU TB) and the mass of the driving unit m_ω.

02 Schematic of the trajectory generation and motion profiles shown form the basis for the ABB's design.

02a Schematic of the control law for the driving unit: P-PI cascade. Shown is the trajectory generation used for transferring the lifting unit of the ABB SC from an initial-rest position to a target position.

02b SC anti-sway control motion profile simulation results of the advanced trajecory generation. Results from the standard motion control (left) and advanced control with the dynamic model (right). The proposed trajectory generation almost completely eliminates mast oscillations.

In 2017, ABB began exploring an anti-pendulum function for ACS880 Position control program.

anti-pendulum solution. With theoretical-, testing- and design phases critical, an intense partnership evolved with each partner doing what they do best. And, because there is usually a gap between what is theoretically possible and what is practically viable, ABB expanded the preliminary results through tests and design iterations, turning them into tangible benefits that are manifested in a new ACS880 Program control anti-pendulum function.

The research projects: an introduction

Having established a collaborative synergy between ABB and JKU, the parallel research projects focused on:

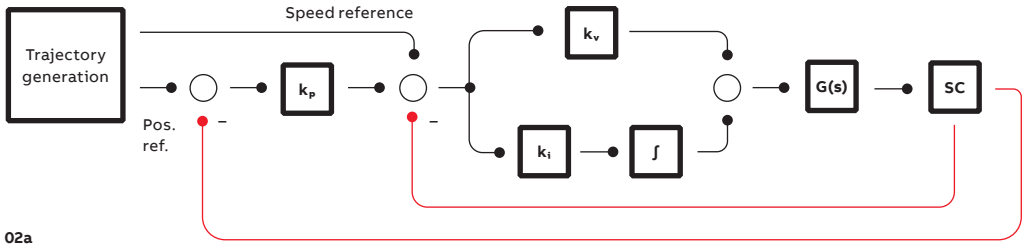
- Developing mathematical models to capture the dynamics of single mast stacker cranes: the JKU test bench (TB), small-scale demonstrator model, and ABB's stacker crane (ABB SC).
- Calibrating the generic model by identifying the parameters of the specific cranes in question.
- Creating a control scheme to generate the position and reference speed for the crane so that it does not oscillate during motion.
- Determining a feedback system so that residual oscillations due to model imperfections or external disturbances are cancelled.

Theoretical basis: mathematical models

To determine the feasibility of creating an anti-pendulum control function, flatness-based trajectory generation approaches were applied to ABB stacker cranes [1,2,3]. Test crane dynamics of both the ABB SC and JKU TB were modeled as a mixed-dimensional system that included partial differential equations (PDEs), ordinary differential equations (ODEs) and consideration of boundary conditions.

In each case, the PDEs are discretized by employing the Rayleigh-Ritz Method so that a pure ODE system is achieved to facilitate ease of system analysis and controller design at a later stage.

Nevertheless, the Rayleigh-Ritz discretization requires the choice of an ansatz function; the



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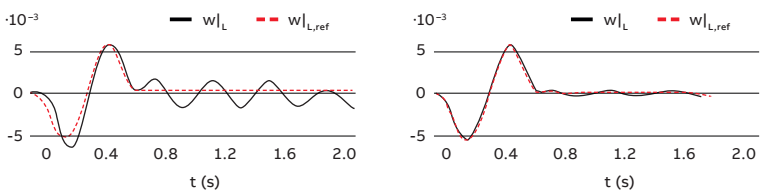

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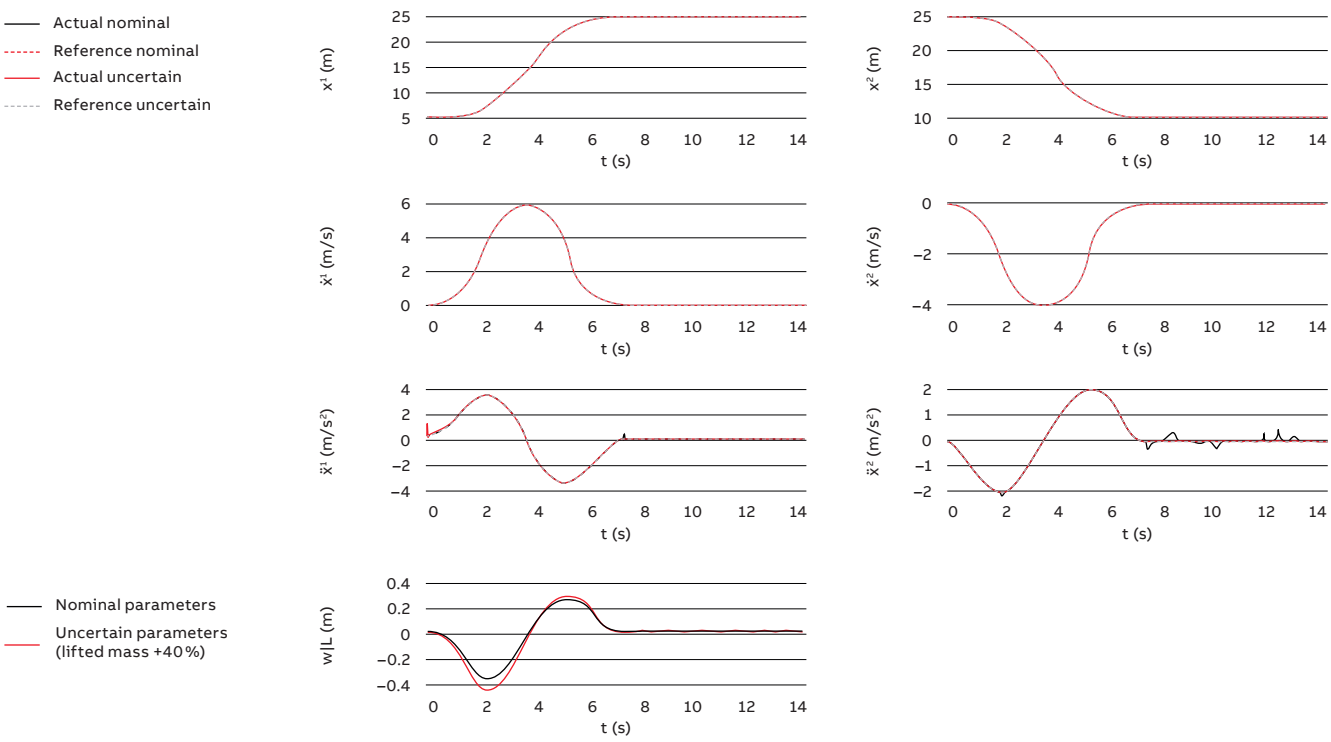


03

structure of which is crucial. Once this function was chosen, the unknown system parameters were determined based on the boundary conditions. Specifically, the equations of motion were derived extending the Hamilton principle to the Lagrangian action functional, which yielded a mixed-dimensional system.

Significantly, in order to obtain equations of a finite-dimensional character, experts applied the Rayleigh-Ritz method (discretization): $\overline{w} = x^1 + \Phi_1(Y) \cdot \overline{q}^1(t)$ where, $\overline{w}$(Y, t) is the absolute position of the beam as a function of height *Y* and time *t*, x^1 is the horizontal position of the driving unit, $\phi_1(Y)$ is the ansatz function (only a function of height *Y*) and, $\overline{q^1}(t)$ is the generalized coordinate (only a function of time). Here, it is notable that $\overline{w}$ is a function of (spatial) height and time, the individual components ϕ_1 and $\overline{q}$ are functions of one dimension only.

The all important ansatz function was determined according to:

$$\Phi_1(Y) = A_1 \cdot \sin(\gamma Y) + B_1 \cdot \cos(\gamma Y) + C_1 \cdot \sinh(\gamma Y) + D_1 \cdot \cosh(\gamma Y)$$

By substituting this equation as well as the ansatz function derived earlier, into the boundary conditions; and deriving the parameters *A, B, C, D, γ* by solving the resulting non-linear system of equations, ABB and JKU could obtain a sound model of the ABB SC →01.

Model calibration: identifying parameters

The sound theoretical model serves as a blueprint for describing the dynamics of stacker cranes. Nonetheless, for the practical application of the model to a specific stacker crane model, parameters must be identified. These unknown parameters were calibrated: flexural rigidity, *EI*, density of the mast, ρA and mast damping coefficient, d_m.

Working with JKU, ABB developed mathematical models to capture the dynamics of single mast stacker cranes.

Using measurement data from a real-world stacker crane fitted with a ACSM1 motion control drive, ABB could derive system parameters. Accelerating the drive unit so that the crane travels at constant speed without oscillating;

03 Results for ABB trajectories as part of the robustification investigations. The ABB trajectories were applied to the JKU TB, which relied on measurement data. Here, a damping injection control law was added to suppress oscillations. Robustness simulation results: m_h, uncertain = $1.4 \cdot m_h$.

04 A depiction of the input shaping used for the profile generation and its basis are shown.

04a Block diagram of the designed 3-step input shaper used for profile generation. Note, profile generation is given by speed reference specified by formula v(t) or as used here as 1D lookup table. Three branches of speed reference, which are shifted in time and scaled by a factor are used. Position reference is derived from integration of the speed reference used.

04b A schematic that illustrates the working principle of input shaping, which uses an initial and a delayed output at time to an oscillating system. As both inputs have the same amplitude (assuming there is no effective damping), the second input will eliminate the oscillation from the first signal and the system will move in a positive direction without oscillation.

then abruptly stopping the system, results in mast oscillations. The lifting unit is moved to two different positions (heights). Once the main oscillation frequency and its exponential decay was determined, a system of nonlinear equations relating the oscillation frequencies and damping ratios to the parameters *EI*, *ρA* and d_m, were solved. Parameters were then applied to a third height as a control.

Having identified mast and drive parameters of the ABB SC, the resultant calibrated dynamic models were then directly used for drive control development.

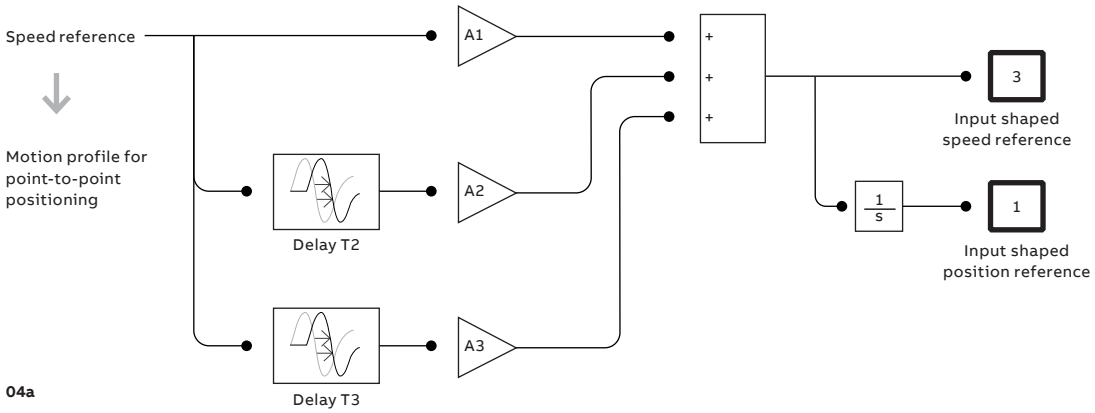
Trajectory tracking and robustness studies

To ensure that oscillation is minimized during crane motion, ABB developed control schemes to generate position and reference speed for the cranes.

ABB's control system superbly and robustly positions the stacker crane with minimal residual oscillation.

Using polynomials to parameterize all system variables by means of flat outputs and derivatives, ABB's resulting equations similar to [3], depend on the flat outputs and their time derivatives; these were implemented in the trajectory generator →02a.

Here, a well-tuned P-PI cascade tracking the references generated by the flatness-based trajectory planner works well if no external



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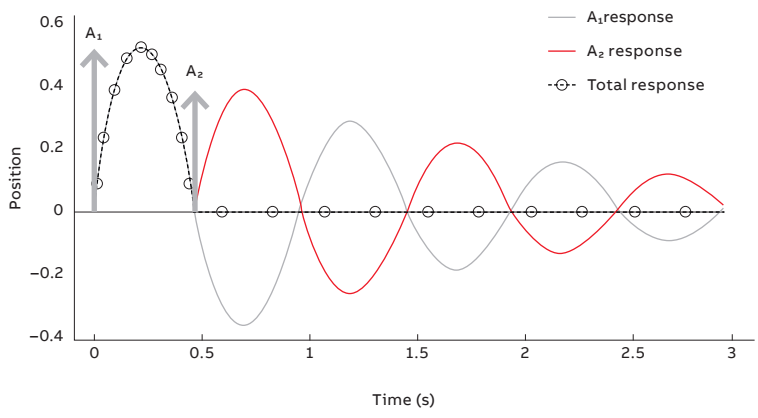

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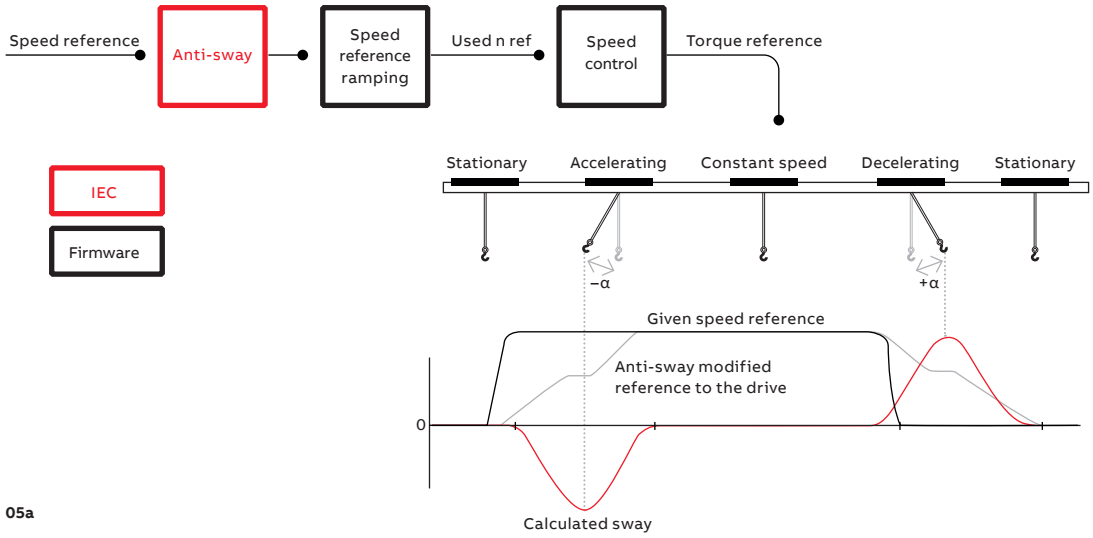

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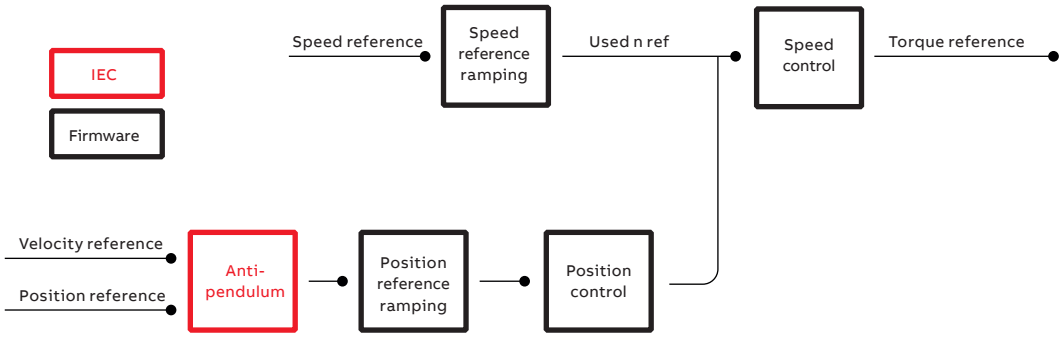


05b

disturbances are present→02b. To mitigate mast oscillations, in case of such disturbances, the cascade was extended with integrated feedback in the driving unit by means of a damping-injection control law [5,6].

By considering lifting-unit mass and beam parameters as uncertain quantities (although they were known) robustness was determined. The result is an amazingly robust system in both the JKU TB and the ABB SC cases →03. Critically, only major system parameter deviations impacted beam oscillations in the JKU TB; slight differences in lifting mass (+/- 10 percent) had almost no impact on the ABB SC; these are excellent results.

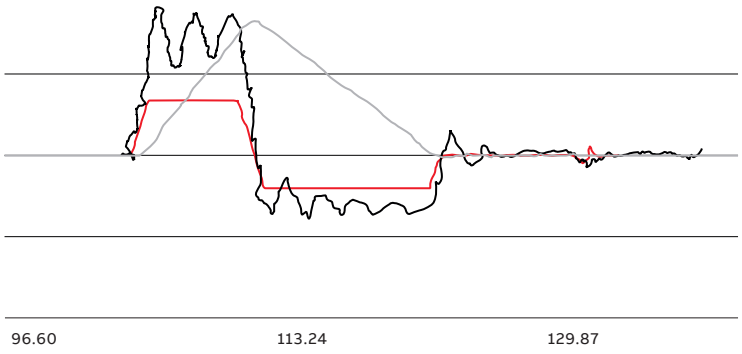
Translating theory into design

ABB strives for the best performing and economical control systems for their customers; this means using the most promising results. Therefore, ABB used the verified modeling →01 and the motion control results →03, as a basis, to develop an anti-pendulum control function that is easy to engineer yet delivers excellent performance and reliability.

ABB's new control method for point-to-point positioning of the stacker crane includes an input shaper →04a, trajectory planning, with the existing control chain of the ACS880 Position control program (motion profile generator, position controller and speed controller) [7,8].

Customers can now accurately move loads, rapidly and affordably in the tallest of warehouses.

Input shapers are designed so that a created command signal tends to cancel its own vibration, reducing the residual swaying of the



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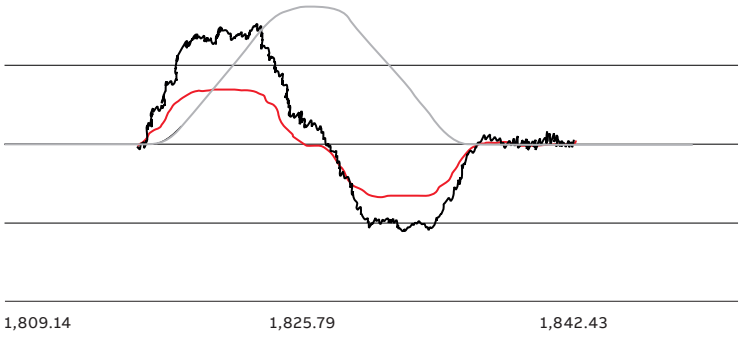

06b

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05 Control schemes are illustrated.

05a ACS880 anti-sway crane control program (for EOT cranes)+N5050 scheme is illustrated in which the reference input changes are divided into two segments where the second is delayed in relation to oscillation cycle time.

05b ACS880 anti-pendulum position control scheme for stacker cranes is similar to the crane control scheme except that the division is into three segments instead of two. This is more robust against oscillation time error.

—
06 Motion profiles generated that illustrate the impact of enabling the anti-pendulum functionality. The black line: 01.10 Motor torque, grey: 86.03 Actual speed, and red: 88.07 is estimated acceleration.

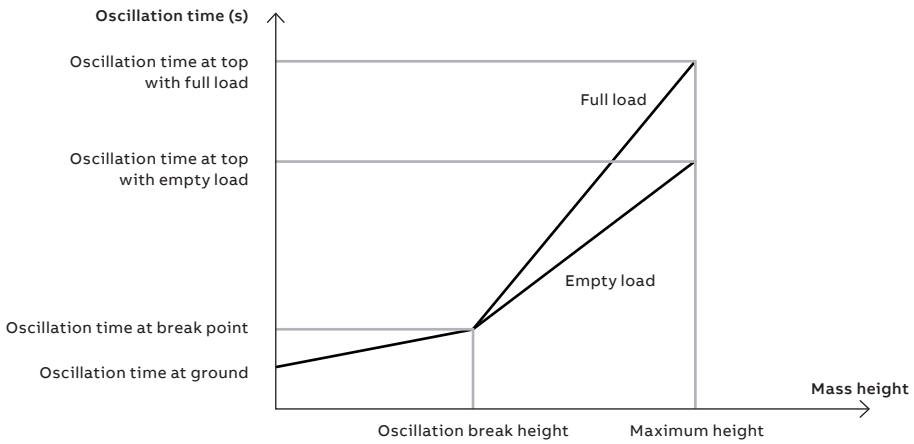
06a Motion profile generated by a basic jerk-limited motion without anti-pendulum functionality.

06b Motion profile generated once the three-step oscillation damping mode is enabled with anti-pendulum functionality.

structure →05a [7]. To achieve this, the damping ratio and the system oscillation, with different heights of the lifting unit (determined based on the dominant resonance frequency), must be known. Here, new system parameters can be obtained during system identification procedures when commissioning the ACS880 drive – a direct benefit to customers.

Because input shaping and damping injection (which dampens the existing residual swaying once the crane has reached its target position) yielded good results, demonstrating excellent performance even when only one function was enabled [7], ABB's experts included only input shaping (with a three-step input shaper) in the final anti-pendulum control function, which is currently available →04–05 [8].

Once the motion profile generator was selected and modified, ABB could design, and successfully implement the system identification procedures



07

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07 Oscillation swing time curves of empty and full loads based on crane target height. Below oscillation break height, mass of the load is not considered to impact the oscillation swing time; above the oscillation break height the mass of the load will have a proportional effect on the oscillation swing time.

for storing and obtaining the needed system parameters ie, damping ratio and swing time.

In this way, ABB's designed control system superbly and robustly positions the stacker crane with the desired dynamics and minimal residual oscillation.

ACS880 Position control anti-pendulum function
Achieving a practical, yet economical, anti-pendulum function with excellent performance was ABB's goal from the onset. By designing a control function with a precise dynamic model of a stacker crane, an accurate calculation of motion is now possible →05b; ABB's resultant ACS880

—

By reducing the time required to stabilize the structure from approximately 3.0 s to 0.25 s, material cycling times can be significantly reduced.

Position control program firmware (+N5700) in a special version with the anti-pendulum function is the culmination of these goals [8]. System stabilization is now possible in as little as 0.25 s.

Here, the standard position reference profile is modified so that it suppresses oscillations initiated by the motion profile itself to a load, acting as an oscillating mass →06. Pendulum suppression performance relies on the calculated system oscillation swing time, the time between two successive peaks of a decaying vibration, calculated for every operating point by the system based on curves (for every mass and height of the load) →07, additional parameters that the user must set, and the damping ratio, a constant given by the user. With the damping ratio ζ calculated using logarithmic decrement:

$$\zeta = \frac{In\frac{A1}{A2}}{2\pi}$$

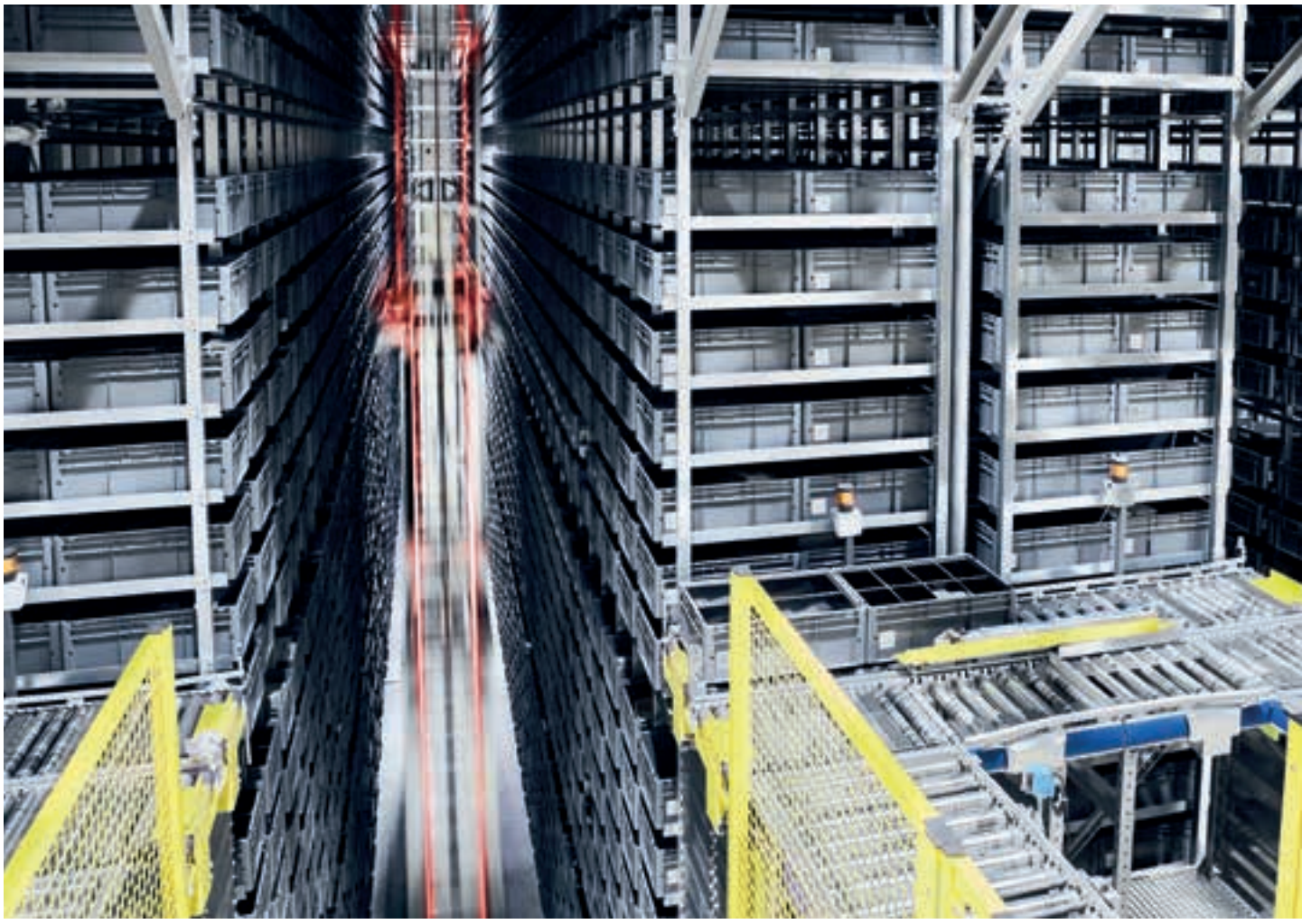
where *A1* and *A2* are the vibration amplitudes at two successive peaks of the decaying vibration; and the other parameters easily obtained or applied, ABB's stacker crane customers will now be able to minimize unwanted oscillations for every storage floor and load encountered.

Delivering viable products
Following the commissioning of the first ACS880 Position control program for stacker cranes in spring of 2019, ABB implemented the anti-pendulum function proto-type. Successfully field-tested at an end-customer site in summer 2020, the first product-level limited-version ACS880 drive control program with an anti-pendulum function was commissioned and released with customized software for a stacker crane customer in early 2021. A new version that targets ABB's general stacker crane customers is currently being developed and is scheduled for release in 2022.

Thanks to the close collaboration with industry and academia, ABB has been able to provide stacker crane customers with an ACS880 Position control program with an anti-pendulum function that fits their needs. Stacker crane systems can now accurately move loads more rapidly and therefore more affordably without fear of oscillations, even in the tallest of warehouses →08. By reducing the time required to stabilize the structure from approximately 3.0 s to 0.25 s, material cycling times can be significantly reduced.

Moving beyond theoretical results to include tests and design iterations, ABB turns ideas into tangible innovative products. This is one way that ABB helps customers handle demanding logistic activity to better meet challenging economic and sustainability targets so important in today's competitive business environment. •

Acknowledgements
This work would not have been possible without the dedication and previous research efforts of many individuals. We would like to extend our gratitude to Tobias Malzer, Markus Schöberl, Martin Staudecker, Matias Niemelä and Stefan Baum.



08

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08 With pressure to decrease material handling cycle times in ever taller warehouses, Stacker crane customers now they can depend on ABB to provide innovative viable solutions, such as the anti-pendulum function, to meet their demanding logistics needs.

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LOGISTICS

Giving customers a clearer view with mySpareParts widget

ABB’s innovative widget and proactive process empowers customers with a window into parts data; this fosters advanced planning and decision-making to reduce excessive downtime, system performance losses and unplanned costs – even preventing failure.

In the parts service sector, too many companies still rely on a reactive parts management strategy in which parts wear down and eventually fail; this can cost up to five times more than using a proactive approach [1]. ABB grasps that digitization can foster a customer's ability to take proactive control of their spare parts management to reduce the risk of unplanned costs, poor performance and downtime associated with perfunctory reactive parts management [2]. After all, why wait until a crucial part fails to replace it? And, why not utilize the technical capabilities emerging from digitization to empower customers to seize control of their part management?

Now, customers can access a set of self-service digital tools for control systems, robots, drives and other ABB products through system-specific applications and widgets on myABB business portal. In 2020, ABB added parts to this product lineup by introducing the mySpareParts widget. This self-service process enables customers to scrutinize their site inventory through the mySpareParts Analyzer, compare this with their installed base in mySpareParts Manager and with what is available in the global ABB supply chain.

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Recognizing the challenges

Frequently, companies mistakenly consider parts separate from the system in which they operate [1]. The reality is that with ever evolving and changing technologies, parts management requires both a systematic approach and systemic understanding. Only then can companies adequately evaluate and assess the criticality of parts in the system. Moreover, not all parts are created equal – some are more critical than others. Malfunction of some parts might pose a safety risk and result in a shut down, others might simply reduce the production speed, while others might adversely affect system performance. Consequently, intrinsic risk must be defined [1]. To have the optimum level of critical spare parts available, customers require a "birds eye view" of their asset and spares ecosystem. By knowing which parts are installed in their system, customers could fully assess and understand the criticality and interdependency of each part in the system and the impact of a failed individual part on the system and its performance. Nevertheless, such a strategic approach to parts management is a balancing act; establishing the comparative importance of parts and analyzing the likelihood of failure or disruption is challenging.

The current state of affairs

By basing decisions predominantly on the cost of parts or their historical usage, many companies underestimate their critical spare part stock by up to 60 percent [3]. The potential cost or financial implications of asset failure, production downtime or reputation damage from an interruption to "normal service" are not considered. This reactive approach to parts management can also have unexpected consequences due to potential supply chain unpredictability. Typically, when the author of this article asks customers about spares, the common response is, "we're good on parts" and the author's reply is how do you know? Many find it challenging to answer that question because there has to be some documentation of the process, in order to reach that conclusion. In practicality what we find is that there are gaps that ABB can address. There are even cases where the customer does have everything that they need which carries validation within itself that they are doing everything correctly today. However, this is not a

In 2020, ABB introduced mySpareParts widget to its digital tools on myABB business portal.

static process, lifecycles and support structures change. This needs to be evaluated on a regular basis.

The failure to plan nurtures a potential for waste of manpower, materials and machine time; and this raises the manufacturers' costs and ultimately the price of a product.

ABB's mySpareParts management solution
The solution to such challenges lies with a comprehensive proactive yet tailored digital parts management approach. With a detailed inventory of the installed-base on-site captured, companies could better define their parts strategy and enact it. Customers also gain from measuring spares holdings value against the cost of potential downtime, suboptimal performance and loss of reputation if customer commitments cannot be met. By evaluating the system under normal operating conditions, customers can understand the supply chain – before costly problems occur. Clearly, a holistic parts management program must understand what will happen when a part fails – before it fails.

Parts management requires both a systematic approach and systemic understanding.

Enter ABB's mySpareParts Manager, a proprietary software platform, designed to generate the customized recommended parts, gap, and supply chain information, along with reports for the identification of risk. This is accomplished by examining important information including:

- Current install base
- Item to part associations
- Site Inventory
- Product lifecycle
- Site parts product and location information
- Parts risk level

mySpareParts widget
The widget gives customers a "birds eye view" of the data needed to make proactive decisions to ensure production availability and prevent or reduce stock-related disruptions. The widget, mySpareParts, is a centralized platform that currently has three views: mySpareParts Analyzer, Recommended Spares and Gap Analysis →01.

mySpareParts Analyzer is a self-service tool that allows customers to upload their existing spare parts inventory and allows ABB to analyze and report to customers →02. Customers gain insights into risk factors →03, lifecycle status and replacement options based on country stock and replaceability, and repairability. A core element of the risk analysis is evaluation of the risk of failure →03. This product takes into account the "intrinsic risk" of each item in a customer's installation. To accomplish this ABB has built a library of risk for over 1.5 million parts using an internally developed proprietary Bayesian model.

ABB's mySpareParts Analyzer, thus, helps companies identify gaps in spare parts inventory to prevent downtime, optimize production, and facilitate strategic thinking around their existing spares inventories.

Inputs from the mySpareParts Analyzer tool and ABB's ServIS install base management tool are combined in the mySpareParts Manager. Customers are provided with two additional views: Recommended Spares and Gap Analysis →01. With Recommended Spares, the customer sees a list of items that ABB recommends to stock based on the customer's site-specific install base and includes important data such as part inventory risk to process as well as lifecycle. Gap Analysis combines the Recommended Spares information with the Analyzer Spare information and proactively searches for missing and excess inventory items. The user can filter information at will. For instance, a customer can filter only those items that are classified as high risk with late life cycle statuses. The customer sees how many of these parts ABB recommends to stock. These reports are delivered in a document called a Parts Fingerprint.

Collaboration for a tailored solution
ABB works together with the customer and the ABB MySpareParts Manager tool to edit all the site-specific information to identify a path forward. The complexity surrounding spare parts does not stop once the optimal spare part holding has been identified. It is essential that a robust and effective inventory management solution is in place to protect these assets. ABB can tailor a spare parts inventory management solution to suit a customer's specific goals, maintenance strategies and operational needs; this ensures critical operational spares will be immediately available where and when they are needed. While ABB's primary option is to always provide spares directly to the customer,

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01 Initial display view from myABB business portal is shown. From here customers can enter any of three tabs titled: Analyzer, Recommended Spares, and Gap Analysis.

02

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02 The initial page display for mySpareParts Analyzer Customers can easily validate their part numbers and rapidly and efficiently cut and paste part numbers and quantities into Excel, receive alerts about data concerns, qualify information via 4 simple questions, and submit data for upload; receiving a confirmation.

03

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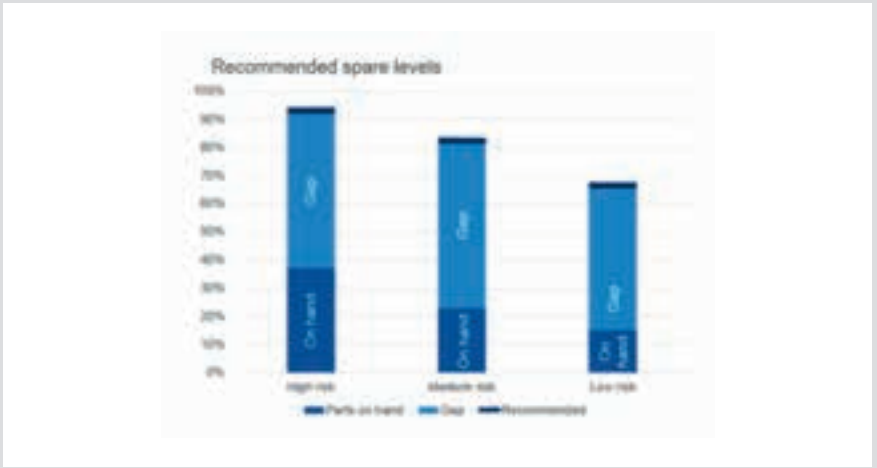
03 An example of a mySpareParts Recommended Spares display; this shows customers their parts inventory risk according to severity, visually and numerically. Customers can easily view other displays, eg, the life cycle status, country stock status, replaceable and repairable.



04

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04 A Parts Fingerprint Analysis display, from a chemical company in Louisiana, USA, showing potential gaps in inventory levels that might increase the risk of control system (and production) downtime.

occasionally a vendor-managed spare parts inventory system may be included in an ABB Service Care Agreement.

Taking analysis one step further
ABB Parts Fingerprint solution is an in-depth systematic process designed to provide customers with a spare holding recommendation for the purpose of arriving at an agreed optimal spares holding. Informed and defined by the customers installed base, risk of part failure to the process at an individual part level, the environment within which the part is operated and the supply chain, this solution allows ABB to share information on customer spare parts; thereby enabling customers to take control of their spare parts strategy and management.

With expertise and understanding of their own parts and equipment, ABB relies on an iterative three stage process to address evolving life cycles and obsolescence: assess, implement and sustain. Outputs include reports for Recommended Spares, Spares Gap Analysis and Supply Chain Analysis. The process captures detailed

05

ABB's mySpareParts Manager generates customized recommended parts, gap, and supply chain information.

equipment configurations down to the part number level. It includes an audit of the existing parts held by the customer and captures quantity and quality information to facilitate improvement recommendations. It also promotes analysis of the supply chain and identifies parts issues proactively →04.

Parts Fingerprint case studies
ABB managers of a chemical company in Louisiana, USA recognized that to ensure maximum production, they needed optimum availability of their existing control system. They needed to know if gaps existed between critical high-risk spares that might be needed and their actual on-site availability. →03. Based on the Parts Fingerprint from ABB's ServicePro Service Management System, ABB helped this customer to understand their parts situation and to decide whether to upgrade their control system, thereby ensuring high production availability. As part of the IAEN Service Account Management initiative, in 2020, ABB Malaysia executed an end-to-end Parts Fingerprint process for a customer →05. Starting with the data collected from the SPDC scan of the ABB's 800xA Power Management System and combining that with the information shared by the customer through the Parts Analyzer. The Parts Fingerprint report showed the installed components- and recommended spare parts quantity, matched the recommendation with the customer inventory gathered from the Parts Analyzer, and highlighted the gaps between recommended parts and actual stock. After a common evaluation of the Parts Fingerprint report, the customer proceeded to supplement the existing stock with the agreed items identified to represent a potential operational risk.

A view to the future
An additional Supply Analysis report view is scheduled for release in 2021. Here, the gaps identified are compared with the supply chain – against the local, regional and main stocking centers – to develop a customized stocking plan. Additionally. a more in-depth analysis of a customer's order history, recent failures, etc. will be possible.

With mySpareParts management solution, customers get the data they need – including

05 A view of a chemical plant in Louisiana, USA, that makes products used in agriculture, cosmetics, food and pharmaceutical. With the Parts Fingerprint analysis the customer could make a sound decision about upgrading their control system.

elements like intrinsic risk, main regional and local stocking plans, lifecycle impact on products and parts, all compared to the products and services for their needs throughout the lifecycle of their plant and product. Moreover, customers understand what is recommended, combined with their current situation, in order to form a plan of action – this facilitates decision making. With the analytical power of ABB's digital toolset, customers are empowered by this proactive approach to systems and parts management to mitigate risks. •

With mySpareParts management solution, customers understand what is recommended – this facilitates decision making.

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LOGISTICS

Workflow mining of operator audit trails

Despite extensive automation of industrial processes, operators often have to intervene manually. These interventions are recorded in various storage locations – such as the plant historian. How can this, currently rarely reused, data be exploited to create operational knowledge for future reuse?

01

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Even though the typical modern process plant is highly automated, manual intervention is still common – ie, human operators monitor the plant state continuously and counteract abnormal situations that endanger safety, environmental footprint, quality and operational efficiency by switching to manual mode and taking appropriate action. Repair and maintenance procedures or regular startups or shutdowns also require manual intervention. Interventions can take minutes or hours and operators can often make the same or very similar intervention over weeks, months or years and take similar action each time.

Systems such as the historian represent a rich, untapped source of potentially valuable data.

For compliance reasons, most process plants have a centralized historian that stores control system operational data. The historian covers event data and signals data generated by controllers, actuators and sensors. Manual interventions are also usually stored in the historian as an audit trail – ie, an event log that records every interaction with the control system, such as setpoint changes, the opening and closing of valves and the startup and shutdown of equipment.

While every intervention is stored in the historian, this data, due partly to its size (and differing formats), is typically not processed further. Even for small plants, the historian can store several hundred thousand events and signals from thousands of sensors every day, often leading to data quantities in the terabyte range.

Systems such as the historian represent a rich, untapped source of potentially valuable data. The

— 01 Workflow mining of otherwise underused plant historian data can help improve operations.

Workflow mining of the manual interventions stored in the historian can allow a better understanding of a plant's behavior.

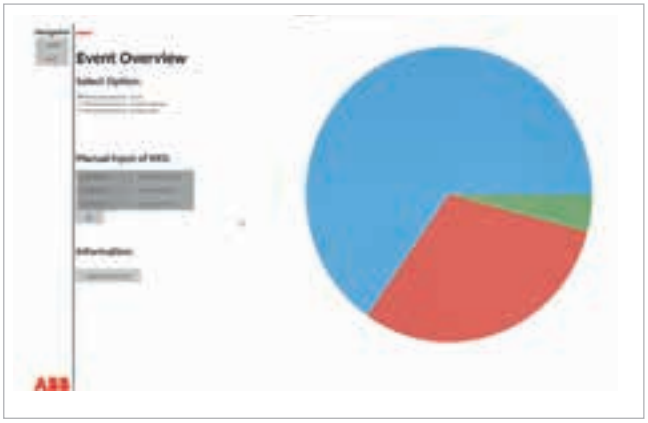
question then arises: Can this data be used to preserve operational knowledge for future reuse? The answer is "yes." Workflow mining is the key.

Workflow mining

Workflow mining of the manual interventions stored in the historian can allow a better understanding of a plant's behavior, deliver insights into solution strategies and enable the assessment of the quality of these strategies. Workflow mining can also generate standardized best practices. Because the information related to manual intervention is scattered and it is not necessarily clear which case-cause data can be grouped or is related to the case in hand, the extraction of manual intervention cases from the process historian is, in itself, a challenge.

In this article, workflow mining on the plant historian is discussed with a specific focus on:

- Identification of cases of manual interventions.
- Identification of the plant state that triggered the manual intervention case.
- Extraction of case classes, which are put into a



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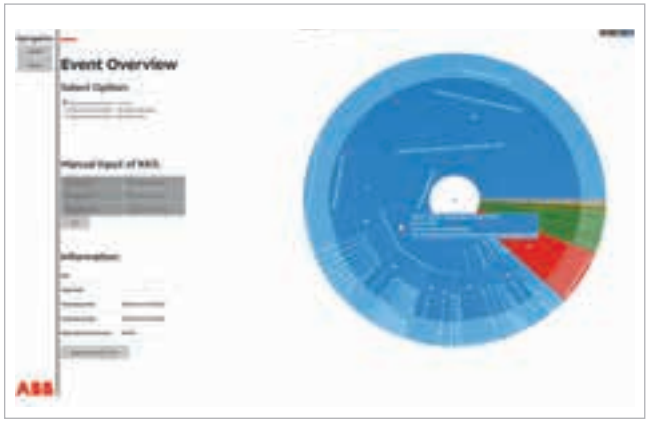


03

workflow mining pipeline, ultimately leading to operator guidance.

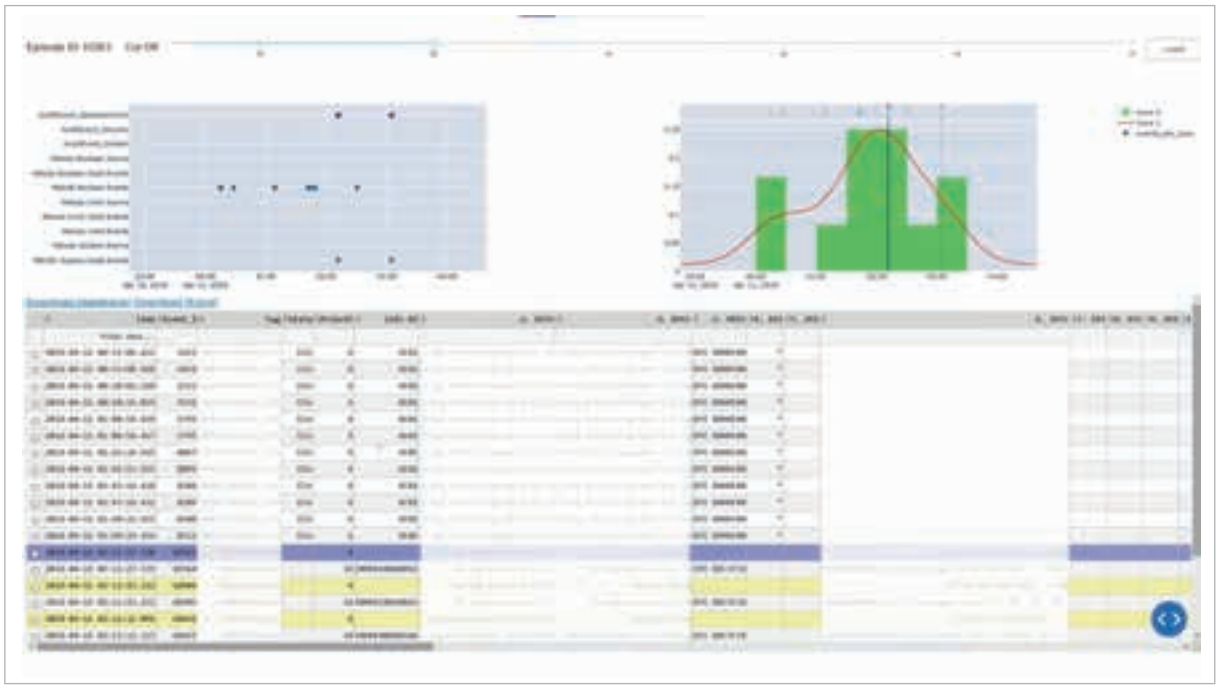
Manual intervention analysis

The first step is to create a tool to identify and display instances of manual interventions and their frequency and duration. This tool queries the audit trail and event database of the plant to provide a list of intervention data. From this data, a "case" must be extracted – ie, a subset of events from the list →02-03. The seed event is included in the subset, as are events that occur a given amount of time before and after the first and the last event, respectively. In other words, case extraction is built upon the notion of temporal isolation.

Case-cause extraction

It is assumed that every case is triggered by a plant state, represented by sensor values, other process-related information and active alarms or events. Therefore, an analysis (a "fingerprint") of the overall system state just before a case is contrasted with a "normal" one to extract the cause of the case. This fingerprinting activity depends highly on the system under investigation. For the process plant associated with the work described here, it was decided to focus on the state of the signals that are part of the case.

The first step is to create a tool to identify and display instances, frequencies and durations of manual interventions.



04

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02 Number and duration of interventions in various regions of the plant.

—
03 One region of the plant can be selected to see where most manual interventions happen.

—
04 Example of a mined episode.

—
05 Example with relation of plant signals and workflow.

For these signals, key performance indicators (KPIs) are generated based on moving-average calculations. In other words, a fingerprint of the sensor values of the plant before the manual intervention is compared to the average “normal” sensor values. Those signals with a difference above a certain threshold compared to the long-term KPIs are candidates for a case cause. Case-cause information is added to the case information.

—

The next step is the generation of step-by-step instructions to rectify the abnormal situation in the future.

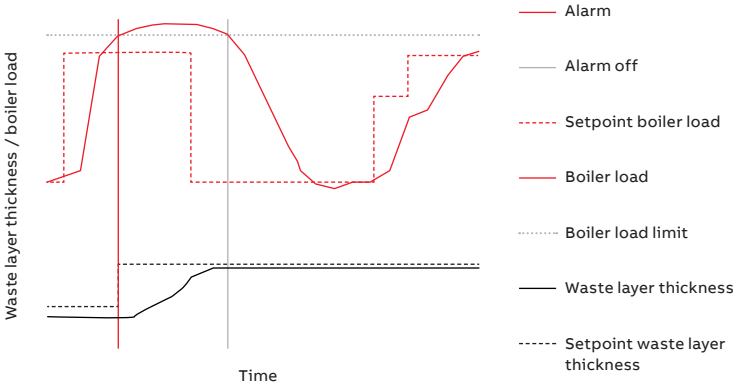
Case clustering

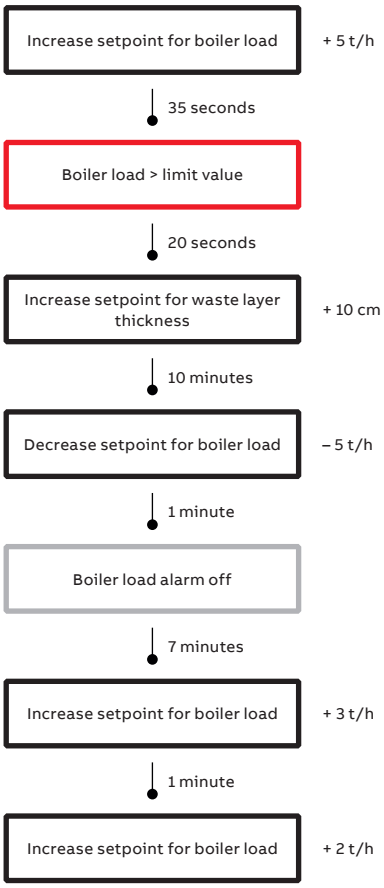
Every extracted case potentially presents a different manual intervention to solve a specific situational issue by following a particular strategy. To prepare for workflow mining, a clustering of those cases that represent similar strategies is applied.

Finding solutions

Once a general understanding of manual interventions has been gained from the audit trail and event database, as described above, solution procedures, so-called episodes, can be examined. →04 shows the four screen elements of a typical episode as displayed in the tool ABB has developed for this task. Along the top is a slider bar that defines how close two interventions need to be to belong to the same episode. Extending this window captures more events, resulting in a much longer solution procedure. The optimization of the length of this event window is a work in progress. The top-left element in →04 shows event types over time; top right is a density plot of events over time; and the bottom half of the screen shows plant events relating to the episode.

After the tool has defined suitable episodes, the next step is the generation of workflows – step-by-step instructions for the operator to rectify the abnormal situation in the future. Similar episodes that represent solutions to the same issue are imported into an external tool to generate a workflow →05. This workflow shows all the different actions taken to address the same problem – here, handling of the burner in a waste





incinerator. →05 includes steps that were rarely executed and these can be filtered out to provide a step-by-step guide that consists of the most frequently executed steps →06. A timing guide can also be generated →07. Before it goes live, the workflow is checked by an expert.

Use by the operator

In the field, when an abnormal situation occurs for which a workflow is available, this workflow will be recommended to the operator. On acceptance, the step-by-step workflow will be shown on a sidebar.

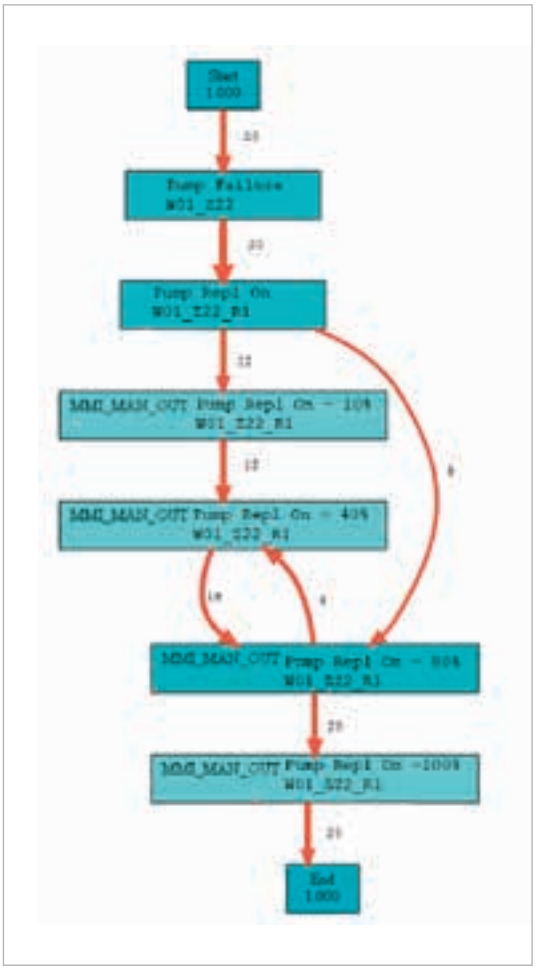
The full process from intervention type selection, case extraction, case cause extraction, case clustering and workflow mining as described above is summarized in →08.

Insights from a mid-sized plant

During the development process, the team worked with a copy of the historian from a medium-sized power plant. The plant stores 8,000 signals in the historian and generates approximately 80 million events per year. The events include the operator's audit trail. The six-month dataset from the historian was used to test different approaches. Discussions with experts further aided the development process.

When an abnormal situation occurs for which a workflow is available, it is recommended to the operator.

→09 shows the large number of alarms triggered in the plant (high alarm numbers are not atypical). Operators have a good understanding of alarms and their relation to the plant state.



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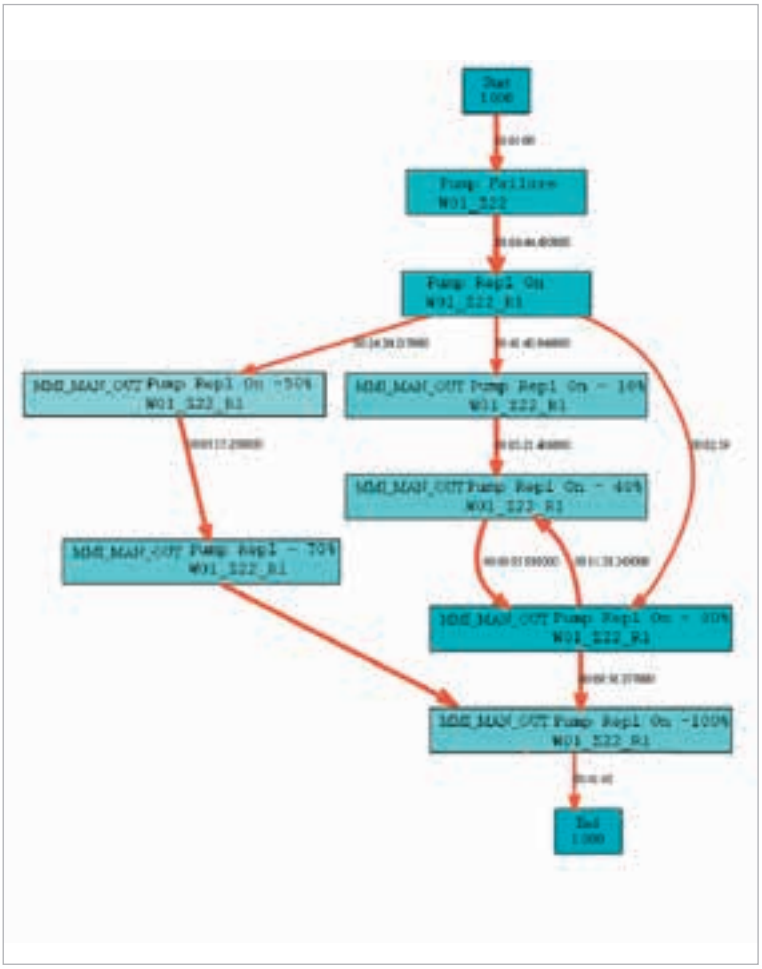

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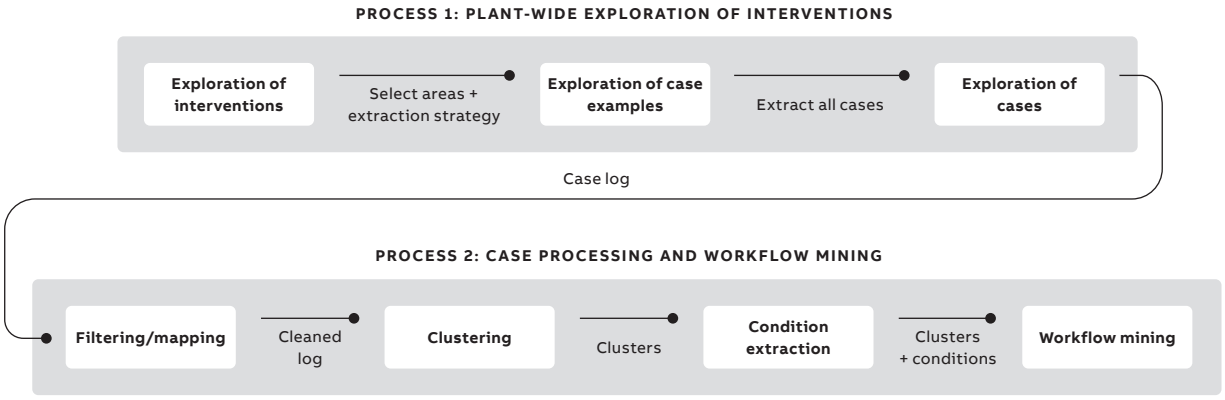

08

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06 Less-frequently used steps can be filtered out.

—
07 The time taken for the steps can also be displayed.

—
08 Applied process of case and workflow mining.

—
09 Event type count. The numbers provide a rough idea of the dimensions to be expected by the analysis and mining activity.

Enhanced process plant operation

Much valuable data is to be found in isolated plant historians. Workflow mining techniques exploit such data to bring benefits to a process plant's operation. Online systems can be created to assist operators when faced with abnormal conditions and future work foresees enhancements through machine-learning approaches and full automation of the workflow mining process.

—

Future enhancements could be machine-learning approaches or full automation of the workflow mining process.

Some related topics require more research – for example, how to realize event localization if the plant tagging scheme does not provide it. Or how to assess the conformity and efficiency of the mined workflows as operators might perform actions that do not conform with the general guidance (eg, ignoring recommended sequences for starts or stops of equipment).

The successful resolution of these, and other, topics will allow plant operators to make more use of the data they already have to enhance the performance of their assets further and improve their financial results. •

Type of Event	Total
AuditEvent_ Acknowledge	70,000
AuditEvent_ OperatorAction	60,000
Alarms	Multiple hundred thousand
Audit Events	Multiple hundred thousand
Boolean Events	15 million
Limit Alarms	Multiple hundred thousand
Limit Audit Events	Few hundred thousand
Limit Events	Multiple hundred thousand
System Alarms	Multiple hundred thousand

09

LOGISTICS

Mine electrification: mapping a course to enhanced sustainability

Technological, environmental and social trends are transforming the world. The mining industry, while traditionally low on the Industry 4.0 curve, is catching up fast – primarily through mine electrification. ABB's eMine™ and its associated Trolley System, as well as its gearless conveyor drives and its expertise in the automation of conveyor systems, are helping mining customers to electrify their equipment from pit to port with fit-for-purpose solutions.

—
01 ABB's eMine™ Trolley System enables vehicles to run on an electric trolley assist line.

Mehrzad Ashnagaran
Mine Electrification and Composite Plant
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ABB has considerable experience around the world supplying large, integrated electrical and control solutions to mining and minerals customers. In addition, the company is enabling miners to transition toward the all-electric mine. The company is committed to partnering with customers and suppliers to reduce their annual CO_2 emissions by at least 100 megatons, equivalent to the annual emissions of 30 million combustion cars, and to achieve carbon neutrality in its own operations by 2030. Mining is currently responsible for around four to seven percent of global greenhouse gas (GHG) emissions – an area in which current methods must change rapidly to meet targets, national regulations and the Paris Agreement.

This article explores two examples in which the journey toward the all-electric mine is already underway. The first examines Canada's Copper Mountain Mining, where ABB is installing an electric haul truck trolley assist infrastructure. The second reports on the introduction of the world's most powerful gearless conveyor system, which is located at the Chuquicamata copper mine in Chile.

An electric transformation in Canada
Without newly mined materials there would be no cellphones, computers, batteries or wind farms. Transitioning to an all-electric mine, which allows extraction of ores with the lowest possible impact on the environment, requires new thinking, as exemplified by ABB's eMine™, a recently launched concept, which is already helping mining customers to electrify their equipment from pit to port with fit-for-purpose solutions to meet operational demands. It is backed by ABB's many decades of real-world experience in electrifying, automating and digitally connecting mine equipment and operations to improve energy usage and overall performance.

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Mining is responsible for around four to seven percent of global greenhouse gas (GHG) emissions.

Complete trolley assist solution
One of eMine's key solutions is the ABB Ability™ eMine Trolley System →01[1], which has already been implemented in a number of countries. The solution enables vehicles to run on an electric trolley assist line instead of using diesel fuel. Most recently, eMine was implemented in British Columbia, Canada, where ABB is working with Copper Mountain Mining →02 [2].

Photo: Boliden


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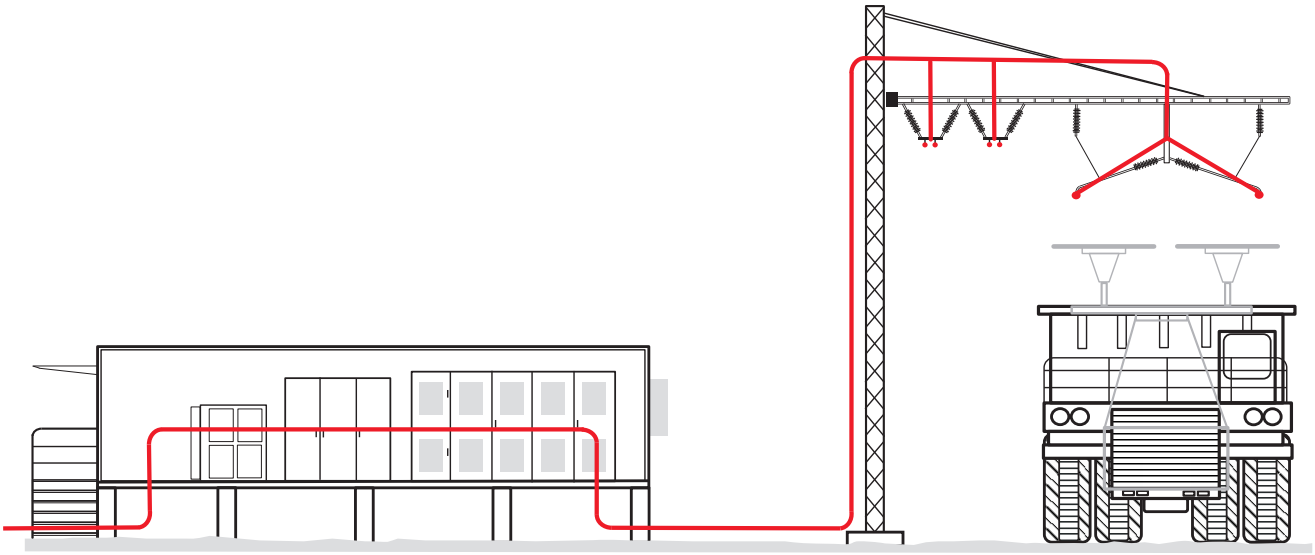

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02 Copper Mountain Mining is located in British Columbia, Canada.

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03 ABB's eMine™ solution dramatically reduces diesel consumption and emissions from haul trucks.

Here, where a conventional open-pit operation produces approximately 45,000 metric tons of copper equivalent per year, ABB is providing a complete trolley assist solution →03. ABB is responsible for all the off-truck trolley assist infrastructure, including an overhead catenary system (OCS) design and a rectifier substation providing more than 12 MW of DC power – as well as engineering, project and construction management, equipment supply and system commissioning.

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The trolley control system supports seamless integration and monitoring of trolley operations and energy consumption.

The trolley control system can provide connectivity to the existing ABB Ability™ 800xA distributed control system (DCS) platform, allowing for seamless integration and monitoring of trolley operations and energy consumption. ABB is also providing OCS components customized for mining applications.

Copper Mountain is expected to initially reduce emissions by seven percent during the first phase of the project, and has set a goal of achieving a 50 percent reduction in CO_2 over five to seven years. The new trolley operation is also expected to improve efficiency; for instance, trucks will be fitted with a pantograph to receive external electric power, thus allowing them to run faster when connected to the trolley system, while using less fuel and requiring less maintenance. As part of the eMine™ concept, ABB has identified six ingredients that will be essential for all-electric operations:

- Interoperability: the ability to have a versatile charging infrastructure application across battery-electric vehicle (BEV) original equipment manufacturers and vehicle types
- Mobility/Flexibility: the ability to implement a point-of-charge infrastructure that allows a mine to adapt as it develops
- Energy Management: the ability to combine power with process control to minimize load peaks and create balanced operation
- Connection Interface: the ability to operate safely at high currents thanks to the use of ruggedized, mine-applicable automated connection devices
- Trolley and Charger Technology: the ability to match charging and trolley infrastructures to the capability of BEV batteries for demanding operations
- Favorable Process and Mine Development: the ability to use alternative mine development approaches such as downhill hauling and/or conveyor, truck and hoist combinations.

The above ingredients, which are empowered by ABB Ability™ MineOptimize [3], are designed to achieve optimal design and operations through the balanced use of energy and resources.

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DRIVING AN EFFICIENCY REVOLUTION IN CHILE

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In remote northern Chile, ABB has been working with German industrial company TAKRAF at Codelco's Chuquicamata mine – the world's largest open-pit copper mine. There, gearless conveyor drives (GCDs) are part of the most powerful belt conveyor system anywhere. They have also become the preferred solution in many mining projects globally.

From engineering design to electrical equipment for power supply and energy distribution, ABB technologies and the expertise needed to integrate them, are evident across the Chuquicamata site →04. However, it is in the automation of a new underground and overland conveyor system that ABB's GCD →05 strengths are highlighted [4, 5, 6].

The mine's belt conveyor system has to perform at high capacity 2,850 meters above sea level in the high desert of the Antofagasta region. The conveyor system is 13 km long and connects underground operations directly to the site's concentrator. Two 20 MW TAKRAF conveyors each lift 11,000 tons per hour (tph) of ore more than 600 meters to reach the surface from the underground mine. The total lift is about 1.2 km, after which the ore is fed to a 15 MW overland conveyor.

GCDs are suited to mining projects that require high drive power. They help to boost the efficiency of higher-capacity belt systems, thus increasing the possible ore throughput, reducing energy usage, cutting equipment downtime and minimizing maintenance costs →06. They are the only economically feasible way to provide enough power to run the Chuquicamata mine's 20 MW conveyors. The limit for an input pinion gearbox on a conveyor is 3-4 MW, so the belt system at the mine would have either required eight motors driving into a gearbox with an output shaft or multiple conveyors with lower power ratings and multiple transfer stations. Either scenario would have required substantially more materials, space, caverns and infrastructure to deliver the requisite power. GCDs were therefore the simplest way to achieve the production output that the customer wanted, with the added benefit of reduced maintenance while driving significant efficiency gains.

With these factors in mind, ABB and TAKRAF commissioned the most powerful GCD system in the world. The system comprises 11 drives with synchronous motors running at speeds of 50-60 rpm, and with a rated power of 5 MW each, resulting in a motor shaft torque of roughly 900 kNm. The total installed drive power for the entire system, including multiple feeder conveyors, is 58 MW.

Switching from open-pit, truck-and-shovel operations to underground operations using the TAKRAF conveyor with ABB GCDs will help mine owner Codelco save roughly 130 million liters of gasoline per year →07. This will be achieved by eliminating the need for 120 large-haul trucks, reducing the mine's CO_2 emissions from 340,000 t per annum to 100,000 t – an estimated saving of approximately 70 percent.

At Chuquicamata, the ABB/TAKRAF solution is connected to the ABB Ability™ 800xA control system for efficient data acquisition, equipment assessment and process optimization. System

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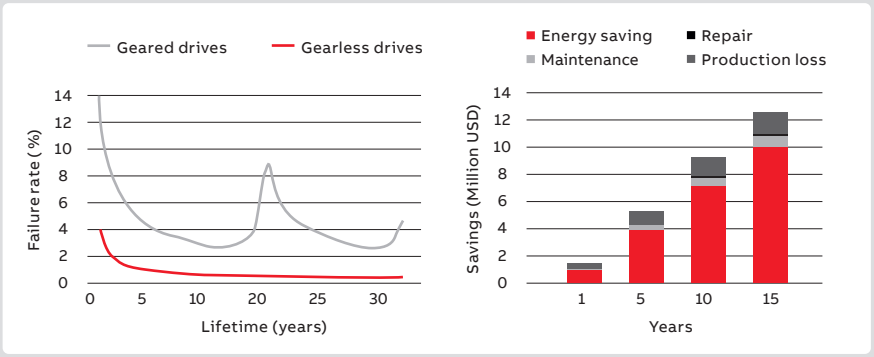

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04 Chuquicamata copper mine in Chile. Commissioning of the world's most powerful gearless conveyor drive system was completed in only four months.

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05 Manufacturing of a gearless conveyor drive.

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06 Gearless conveyor drives have a 50 percent lower failure rate than geared versions. They also benefit from a longer service life and lower energy demand.

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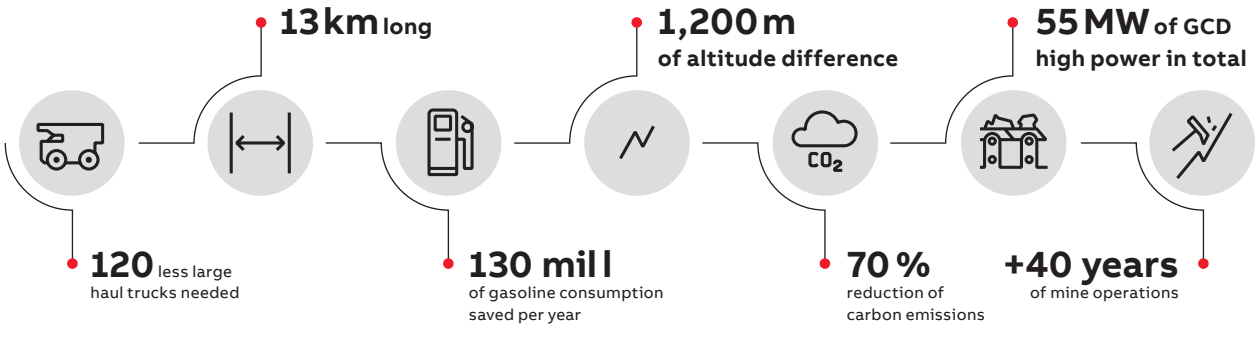
07 A statistical overview of the world's most powerful belt conveyor system for underground mining.

800xA monitors and collects data from multiple sensors embedded in the motor drive system, searching for anomalies and identifying maintenance needs. The project is expected to extend operations for the next 40 years.

Efficiency requirements for medium power GCDs in the 1-10 MW range (total conveying power) are expected to increase in coming years. In view of this, ABB is responding with technologies designed to reduce the cost per ton of production, thus helping customers stay competitive. Compared with gearbox-led solutions, GCDs are energy efficient and produce less noise. On the other hand, drives containing gearboxes with multiple moving parts turning at 1,000 rpm or higher can be very loud and run the risk of exceeding the EU's noise emissions limit of 85 dB(A) (A-weighted decibels).

To avoid such problems, as part of an ongoing upgrade project in the Czech Republic, ABB is utilizing its latest medium power GCDs. By updating shaft mounted geared drives on an existing conveyor system equipped with GCDs powered by synchronous permanent magnet motors, the mine owner will be able to meet EU noise emission limits, as well as prevent frequent failures of the existing drives due to vibration issues. Using GCDs at around 50 rpm with low noise coolers limits noise emissions from the drive unit to less than 75 dBA, giving the mine all the benefits of gearless drives while negating the need for noise encapsulation (housing around the whole geared drive unit) or noise protection walls along the conveyor system. Such GCDs are 5-8 percent more energy efficient and have lower CO_2 emissions than gearbox-led solutions. GCDs also offer a higher level of safety as they require no combustibles or hazardous liquids such as gearbox oil, but instead use a water-based cooling liquid.

GCDs are being deployed in complex and often world-class projects. They can provide many benefits for mine operators by helping to increase efficiency and reduce energy usage, equipment downtime, maintenance costs and noise. Together with solutions including augmented/mixed reality collaboration applications, advanced data analytics, AI tools and machine learning, mining companies and their technology partners are set to further increase the efficiency of operations, however remote or challenging. •



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LOGISTICS

Precision monitoring of marine emissions

Regulations governing the shipping industry’s fuel efficiency, greenhouse gas emissions, and ballast water treatment are becoming increasingly stringent. ABB provides robust solutions based on reliable, highly accurate and durable sensors.

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01 ABB offers solutions for the shipping industry ranging from integrated power and propulsion systems, fuel and combustion management, to emission monitoring and ballast water treatment.

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02 Compared to volume flow information, mass flow information is preferred because it is independent of physical influences.

Each year, approximately 11 billion tons of goods are transported by ship, representing about 1.5 tons per person based on the current global population [1]. However, although shipping is responsible for the release of less greenhouse gas (GHG) per ton-kilometer of cargo transported than other forms of transportation, ships contribute about 2.9 percent of the world's total CO_2 emissions [2] – a percentage that is growing steadily as more and more goods are transported by sea.

In view of these trends, the International Maritime Organization, a United Nations agency responsible for regulating shipping, has set a global target of cutting annual emissions by at least 50 percent by 2050 relative to 2008 levels [3]. Furthermore, the shipping industry itself has every reason to increase its efficiency since approximately 50 percent of a ship's total operational costs are fuel costs [4]. To manage fuel consumption responsibly, considering environmental, economic and legal factors, requires innovative fuel management and emissions monitoring systems based on reliable, highly accurate and durable sensors →01 [5].

Coriolis mass flowmeters

Propelling today's huge container ships requires vast amounts of fuel. The amount of energy generated by that fuel is directly related to the mass of the fuel. Therefore, when it comes to highly accurate energy management, direct mass fuel flow measurement is essential. ABB's Coriolis mass flowmeters are state-of-the-art instruments that use the Coriolis force →02 to measure the mass flowrate of any kind of fluid with utmost precision.

ABB's mass flowmeters use the Coriolis force to measure the mass flowrate of any kind of fluid with utmost precision.

Here, a given fluid flows through vibrating tubes, generating a Coriolis force that creates a phase shift of the vibration between inlet and outlet. As there are no moving parts in the fluid, no wear occurs, and maintenance is reduced to a minimum.

In the past, onboard flowmeters suffered from vibration-related issues. However, the new CoriolisMaster, uses high operational frequencies that are impervious to any possible vibrational noise onboard ships. Thanks to this development, it is possible to gain DNV approval for the meters even when they are installed in harsh marine environments

In addition, possible mechanical stresses from onboard installations have no influence on the flowmeter's rugged housing →03, which is designed to decouple outer installation forces of up to 40 tons. Besides traditional current or pulse outputs, fast Modbus communication outputs are available, ensuring seamless

CORIOLIS MEASURING PRINCIPLE

When it comes to cost and material balance calculations, mass flow information is preferred in technical processes because it is independent of physical influences when compared with volume flow information. Pressure, density, temperature, and viscosity do not change the mass. Therefore, the mass flow rate is the favored measured variable. Mass can only be measured indirectly, eg with the help of Newton's second law of motion, which states that a force acting on a mass produces acceleration (F=ma). How can the mass of a liquid be determined using this relationship? One can accelerate the liquid in a rotating (or oscillating) system and measure the inertial effects. This physical effect was discovered by the French mathematician Gustave-Gaspard Coriolis in 1835.

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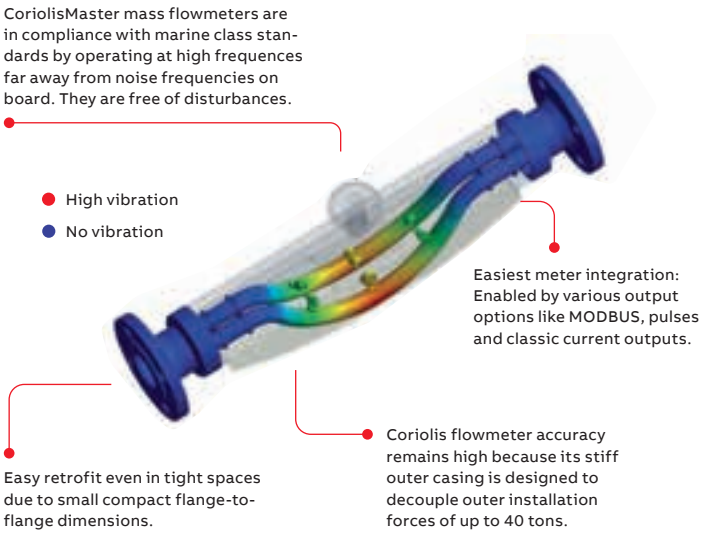

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integration with any kind of ABB fuel efficiency system. This data link provides direct access to all kinds of measurement values, such as flow, density, temperature and concentration, as well as diagnostics information and remote access.

Achieving tighter decarbonization targets
Only one year after new International Maritime Organization emission limits on sulfur and nitrous oxide became effective worldwide in January 2020, ABB launched a continuous emissions monitoring solution. Known as CEMcaptain [6, 7], the solution is designed to help the shipping industry meet the new regulations, thereby becoming more sustainable and achieving new decarbonization targets →04. This step brings emission monitoring for maritime air pollution closely in line with shore-based regulations for power plants, cement works and oil refineries – areas in which CEMS have been used for decades.

CEMCaptain is a multi-component analyzer system that provides continuous, real-time measurement of emissions.

Designed with busy mariners and changing crews in mind, CEMcaptain is a multi-component analyzer system that continuously provides real-time data offering reliable, highly stable measurement of emissions. Operating in even the harshest of conditions, it integrates analyzer modules and sample handling components in a standalone cabinet, making installation easy.

CEMcaptain was designed specifically for marine environments and is suitable for ambient temperatures of up to 55°C, as well as high levels of vibration resistance. It is protected against soot ingress with an innovative filter solution and has a back-purging option for easy integration and alignment with scrubber operation procedures.

Equipped with ABB's renowned Uras26 non-dispersive IR gas analyzer, CEMcaptain simultaneously and continuously measures sulfur dioxide (SO_2) and carbon dioxide (CO_2) in line with regulation requirements. Each analyzer has two separate gas paths to allow for separate measurement streams, with up to four different components per analyzer module.

CEMcaptain's measurement and digital capabilities increase on-board safety, provide process optimization, and substantially reduce ownership costs. By consistently achieving uptimes of 98 percent or more, the new system not only requires minimal maintenance but also saves time otherwise spent on handling non-compliance issues. The system benefits from innovations in on-site and remote digital services, thus providing the industry with a digital toolbox that increases regulatory compliance and operational efficiency.

Fast fault reporting, diagnosis and repair are achieved via CEMcaptain's on-site and remote digital services, which help operators get close to 100 percent availability for their gas analysis instrumentation. Dynamic QR codes are integrated into the system display panel and all relevant diagnostic information can be collected from the analyzer via a scanned code and transferred to ABB support. This means that maritime instrumentation technicians can send real-time information to an ABB service expert to get immediate guidance on appropriate maintenance.

ABB Ability™ Remote Assistance with secured connectivity direct to ABB support is also offered for real-time solutions to problems. These features reduce the need for training fresh crews; they also cut the number of experts required on board and increase on-board safety by reducing crew exposure to emissions.

ABB has more than 60,000 Continuous Emissions Monitoring Systems (CEMS) installed in over 100 countries and draws on 60 years of experience in emissions monitoring.

Ballast water treatment
In addition to new and stricter regulations covering marine fuel efficiency and sulfur and

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03 Application benefits of the ABB Coriolis mass flowmeter.

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04 CEMcaptain is designed to help the shipping industry meet new emissions regulations.

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nitrous oxide emissions, new regulations have also driven the need for ballast water treatment and measurement. Ballast water is used to stabilize vessels when they are not fully loaded. However, water that is taken in at one port and released at another can cause the introduction of non-indigenous organisms into ecosystems. As a result, untreated ballast water is now highly regulated, meaning that all vessels must install a ballast water treatment system.

Historically, however, such systems have been mechanical and thus negatively affected by the presence of mussels, sand and other particles in ballast water. This limits a meter's lifespan and results in increased maintenance and replacement costs. ABB's solution is its electromagnetic ProcessMaster flowmeter [8], which has no rotating parts reaching into the pipe that can wear out and cause pressure loss. In addition, a highly abrasion-resistant sensor liner material makes ProcessMaster ideal for ballast water treatment. •

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ABB has more than 60,000 Continuous Emissions Monitoring Systems (CEMS) installed in over 100 countries.

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LOGISTICS

Fine tuning hydrogen fuel cell research

As governments worldwide seek new ways to decarbonize transport, ABB has developed a product that will help the automotive industry optimize the use of hydrogen to power electric drive trains.

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THE MEASURING PRINCIPLE

Thermal mass flow meters evaluate the flow-dependent cooling of a heated resistor as a measuring signal. The gas to be measured flows around two temperature-sensitive resistors, measuring resistor and heating resistor, which are part of an electrical bridge circuit. Due to the selected resistance ratio, the heating resistor is heated by the heating current I_H. The measuring resistor assumes the temperature of the gas. The heating current I_H is preset by an electronic control circuit so that a constant temperature difference between the heated resistor and the temperature of the gas is established.

The electrical power generated in the heating resistor exactly compensates for its heat loss to the flow. Since this heat loss depends on the number of particles impinging on the surface of the heating resistor, the heating current I_H represents a direct measure of the mass flow rate. Additional pressure and temperature compensation is not necessary.

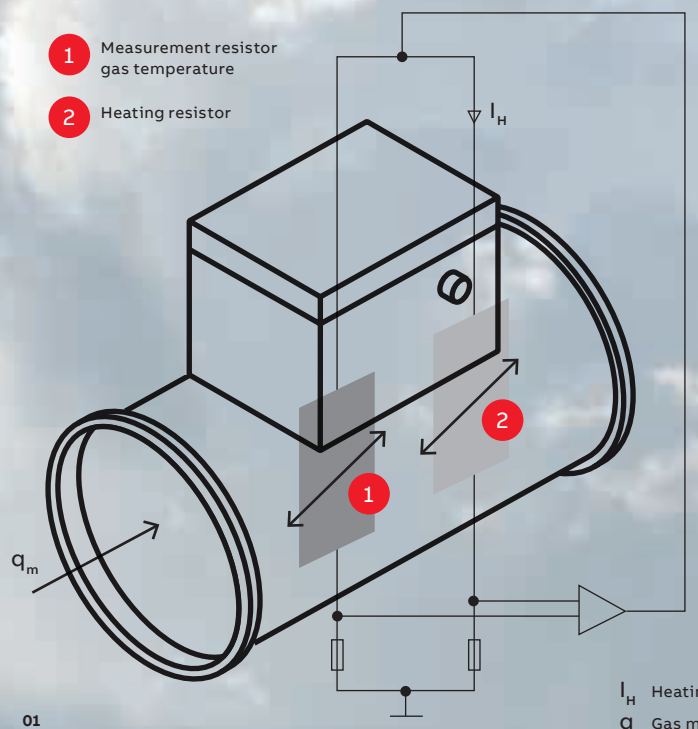

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Photo: ©istock/Jurkos

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01 Hydrogen offers one of the most promising ways to eliminate carbon emissions from heavy transport such as trucks and buses.

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02 ABB's new flowmeter measures the amount of air that enters a fuel cell to combine with hydrogen.

02

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The Sensyflow FMT700-P Compact thermal mass flowmeter is the latest addition to a product range already proven for measuring engine intake air on test benches [1]. Accurate to 0.8 percent of reading, across extendable and adjustable measuring ranges, this new flowmeter is ideally suited to fine-tuning the efficiency of fuel cells that combine hydrogen and air to produce electrical power, emitting only water in the process.

Originally developed to test conventional turbochargers and components such as throttle valves, intake fans and air filters, the P-Compact flowmeter can analyze the performance of hydrogen fuel cells and is therefore of great interest to the automotive industry because hydrogen offers one of the most promising ways to eliminate carbon emissions from heavy transport such as trucks and buses →01.

The flowmeter measures the mass of streaming gases directly in the unit in kg/h, meaning that results are immediately comparable because they do not have to be compensated. The device is also highly accurate over a wide measuring range of 80 to 5000 kg/h for a device with a diameter of 200 mm. In a hydrogen fuel cell test, it will measure the amount of air that enters the fuel cell to combine with hydrogen →02, and the response time in less than 25 milliseconds, which makes it ideally suited for detecting rapid load changes.

The P Compact flowmeter is compatible with other products in the Sensyflow range and is as well suited to conventional engine research as it is to analyzing hydrogen fuel cell performance. The device's compact design integrates supply and evaluation functionalities, making it easy

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The flowmeter measures the mass of streaming gases and is highly accurate.

to install with just one cable. Thanks to its unrivalled response time, the device is used by leading car manufacturers worldwide to measure intake air [2] in quality assurance, test bench applications, and research and development. •

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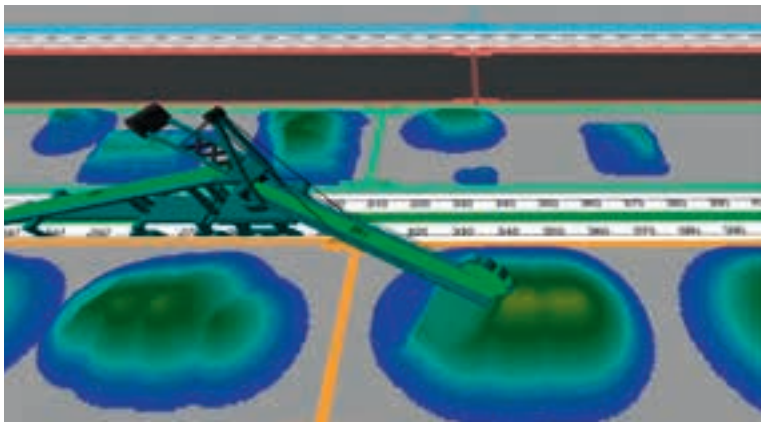
LOGISTICS

Optimizing stockyard operations

Smart components and state-of-the-art software in stockyards are gathering data about the status, operational health and locations of machines and processes. The resulting “digital twins” – virtual copies of machines, processes and entire facilities – are enabling real-time supervision, planning, automated reporting and simulation of stockyards, thus opening the door to fully automated and autonomous operation.



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01 Thanks to the IIoT, digital twins have access to unfathomably large data sets.

Stockyards connect consecutive steps in material transportation chains at mines, rail terminals, ports and plants →01. These facilities provide a buffer of materials between steps in worldwide transportation and logistics chains. Stockyards are also used for mixing and blending different types or qualities of material to achieve required specifications.

In order for such facilities and processes to be managed from a central control room, the operator must have an uninterrupted, real-time overview of how much material of a given type and quality is at any given spot, whether it is in a surge bin, on a belt or on a stockpile.

To achieve such an overview, the physical systems, processes and services in a stockyard must be outfitted with smart components and state-of-the-art monitoring software. Such components and software gather data about the real-time status, working condition and locations of machines and processes and combine the resulting data with virtual versions of the machines and their facilities. This makes it possible for data stored in different places to be accessed from a common digital twin directory, thus opening the door to real-time optimization, job reporting, reduced downtime and the use of simulations to plan for the future.

While the use of simulations is nothing new, they have historically relied on relatively small data sets or assumptions about conditions when making predictions. Digital twins, however, have access to unfathomably large data sets thanks to the Industrial Internet of Things (IIoT).

ABB's Ability™ Stockyard Management System (SYMS) provides real-time information regarding handled materials, real-time verification of data, and industry-leading support for operators to improve overall performance →02. It is a configurable system that can be used to provide a digital twin of a facility's complete material handling chain, including the status of all connected machines and its materials transportation infrastructure.

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ABB's Ability™ Stockyard Management System provides real-time information regarding handled materials.

SYMS allows the flows of different materials to be modelled across belt conveyors and transportation equipment and combined with material properties and quality information via automated data interfaces. Furthermore, all of the resulting

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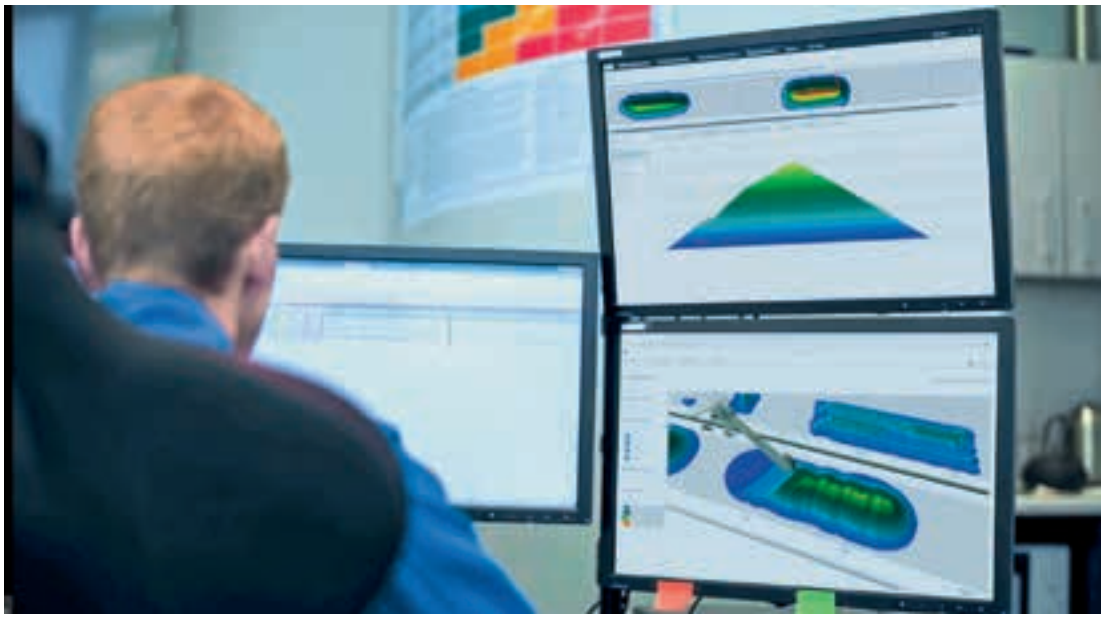

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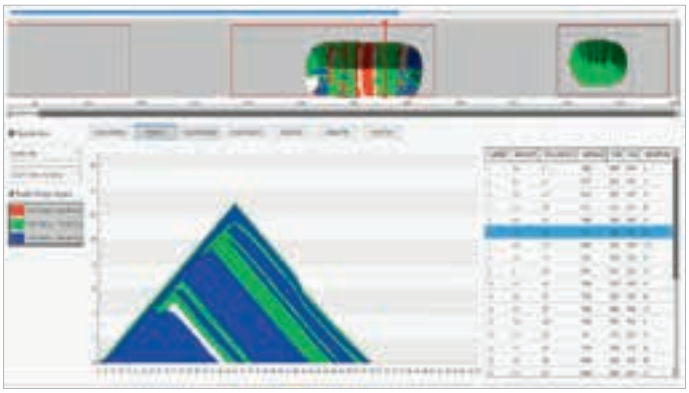

03

data can be used for operational optimization, such as efficient space utilization in a yard, better planning and scheduling, and more accurate mixing and blending processes. Additional advantages include faster loading and unloading, improved safety, improved accuracy, and reduced energy and labor costs.

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The data generated by SYMS can be used for operational optimization such as improved space utilization and planning.

From NASA to digital twins

The concept of creating an identical copy of a real object in the virtual world has been around ever since NASA applied the idea to figuring out how to rescue a space mission →04. But it is thanks to the IIoT that it has become cost-effective to implement a new kind of bridge between the physical and digital worlds.

A digital twin is an evolving digital profile of the historical and current behavior of a physical object or process that helps optimize business performance. Digital twins are based on massive, cumulative, real-time, real-world data measurements across an array of dimensions.

When applied to managing mining operations, ports or steel plants, the digital twin of a material handling chain provides the operator with a real-time inventory. Material tracking is realized by evaluating all available process data from a facility's controllers or central control system. Based on the speed of conveyors, materials are tracked by tonnage or volume in material segments.

All available material properties and quality information can then be associated with the material via automated data interfaces. As this

takes place, a calculated pile stacking model is built up based on the tracked belt segments; this acts as a digital twin of the stockyard in the database. This digital twin provides the operator with an inventory overview at any time, without needing to do an extra survey.

Tracking materials and predicting flows

To meet goals such as optimized yard utilization, planning, scheduling, and, ultimately, fully autonomous yard machine operation, SYMS provides a stockyard overview and an intuitive multifunction 3D client. For instance, SYMS's "slice view" feature →03 makes it possible to look inside a pile to check its material mix and quality. If the properties of the material appear to have changed as a result of excessively long storage, a warning will be displayed.

SYMS generates automated reports, enabling simplified, customer-specific shift and performance evaluations.

Concepts such as just-in-time and just-in-sequence, which have driven the automotive industry to steadily increasing levels of efficiency, are thus becoming available for bulk material handling logistics thanks to the continuing evolution and refinement of ABB's Ability™ Stockyard Management System.

All in all, SYMS allows users to optimize their operations by tracking materials and predicting their flows. This makes it possible to plan materials handling, including mixing and blending on belts.

The system generates automated reports, which enable simplified and fully customer-specific shift and performance evaluations. It offers a distributed service architecture that enables partly standardized interfaces, fully configurable functionality features and user customization. User management can be integrated with an existing plant infrastructure, which enables a seamless synchronization of all users and their rights.

Finally, in case something fails to go as expected, a standardized plan-handling tool lets users receive plans, check their details, place alternative plans in a queue, and switch to them if necessary. •

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02 SYMS is a configurable system that can be used to digitize a facility's complete materials handling chain.

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03 SYMS' "slice view" feature makes it possible to look inside a pile to check its material mix and quality.

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04 Evolution of the digital twin definition.

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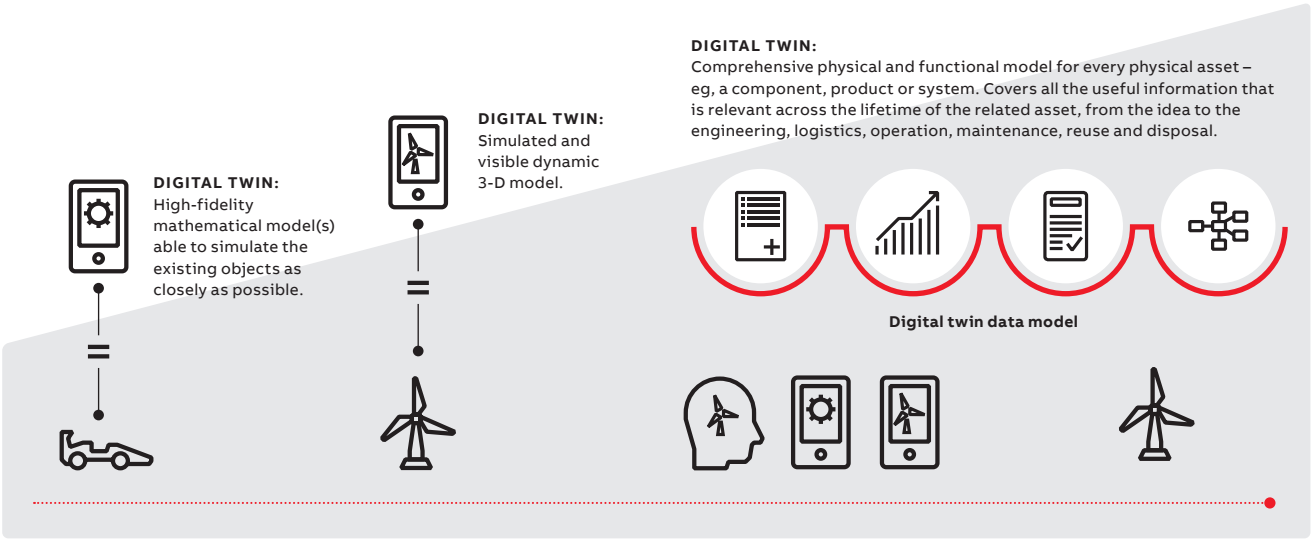

LOGISTICS

Mining: how information is transforming materials handling

Although simulation technology is nothing new, it has historically relied on relatively small data sets when making predictions. But with ABB's Ability™ Stockyard Management System (SYMS), which is essentially a digital twin of a facility, operators have access to unfathomably large data sets that allow the customer to combine each cubic meter of material processed with information regarding material quality and location as well as energy consumption in real time. The result is a technology that has become a business imperative in materials handling and process industries – a vast improvement over competing "boutique" software applications.

AR How does ABB's Ability™ Stockyard Management System complement the company's other customer solutions?

AH ABB has been involved in stockyard management since approximately 2000 when it developed a customized solution for blending different types of coal. From the beginning, the idea was to have a software system that would be an enabler for automation and electrification and that would complement our expertise in managing huge machines, excavators, and stacker/reclaimers. Over the years, ABB reached a whole new level of this technology through its Stockyard Management System (SYMS). Today, the company offers many capabilities that go far beyond blending

ABB not only serves the mining sector, but also steel foundries, cement and fertilizer producers and even port operators.

products for power plants. Its offering now serves not only the mining sector, but also steel foundries, cement producers, fertilizer producers and even port operators. Many customers use SYMS hand in hand with their manufacturing execution systems (MES). This puts ABB in a position to not only provide automation expertise, but expertise in operations management and instrumentation.

AR How does the ABB Ability™ Stockyard Management System compare with competing systems in terms of customer benefits?

AH ABB's unique selling point is that, rather than looking at an operation in terms of individual machines, it provides a digital twin of an entire bulk yard operation – even for customers who have several sites. Our perspective is tailored mainly to customers who plan to optimize their bulk yard utilization as well as their materials' quality. We also address customers who are investing in fully automated and / or remotely operated stockyards.

Such customers have two options. They can turn to 'boutique' software that only monitors what automated systems are doing and estimates the quantities of raw materials at hand, or they can come to ABB and get the most accurate and validated digital twin of their facility – a digital twin, by the way, that can be upgraded to autonomous machine operation.

SYMS calculates everything to each cubic meter using a cuboid model and connects this with data generated by connected instrumentation such as, for instance, a highly customized laser scanner. These two data sets are compared,

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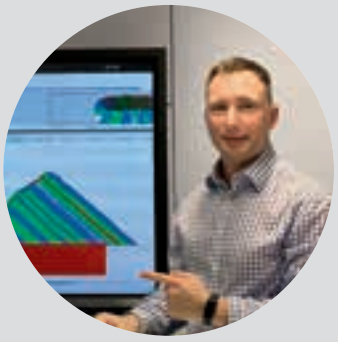
The customer can combine each cubic meter with information such as quality of material and energy use in real time.

resulting in a high level of accuracy. It is the difference between a checks-and-balances system and a blurry estimate. In addition, with ABB's solution, the customer can combine each



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Andre Herzog holds an advanced degree in electrical engineering. Before joining ABB in 2009, he worked at GE and KSB in senior project management and business development. Today, Andre is product manager, Digital Material Handling for ABB and is responsible for digital applications that optimize materials handling primarily for stockyard operations.

cubic meter with information such as quality of material and energy consumption in real time.

AR Quantifying the energy demand represented by each ton or cubic meter must involve tracking the individual and collective operational efficiency of many machines in real time. Is that what SYMS does?

AH The software is able to track how much energy is needed to move materials around a stockyard. In addition, ABB's Performance Analyzer can evaluate the efficiency of all the machines at a site. If a machine begins operating below its specs, Maintenance is alerted. The software is autonomous-operations-ready, which means that if the user decides to run machines autonomously, they do not need new software, only some add-ons. This is a huge advantage that will become available this year. New sites will have the option of being fully autonomous from day one. Older sites will be able to upgrade to a level where a computer system runs machinery instead of a person.

With more and more historical information, operators will be able to make predictions that support future planning.

AR As increasing levels of stockyard autonomy are reached, can operators expect to see maintenance costs decline?

AH ABB's autonomous system takes very good care of machines and their movements. Keep in mind that an operator may be handling a $20 million machine, so if he or she has a bad day then the company and its owners may have a bad year. SYMS makes machine movements much smoother and if it recognizes danger a whole sequence of movements will be stopped.

In addition, with ABB Ability™ Performance Optimization, which we mentioned earlier, we can track and evaluate each machine's operations from a historical perspective. The resulting data allows operators to identify a machine that is not working as it should be. This gives a stockyard a huge advantage because it is like having a doctor constantly tracking patients' vital signs. KPIs are set and tracked in the Stockyard Management System environment. Furthermore, as more and more historical information is developed, operators will be able to make predictions that support future planning from different perspectives.

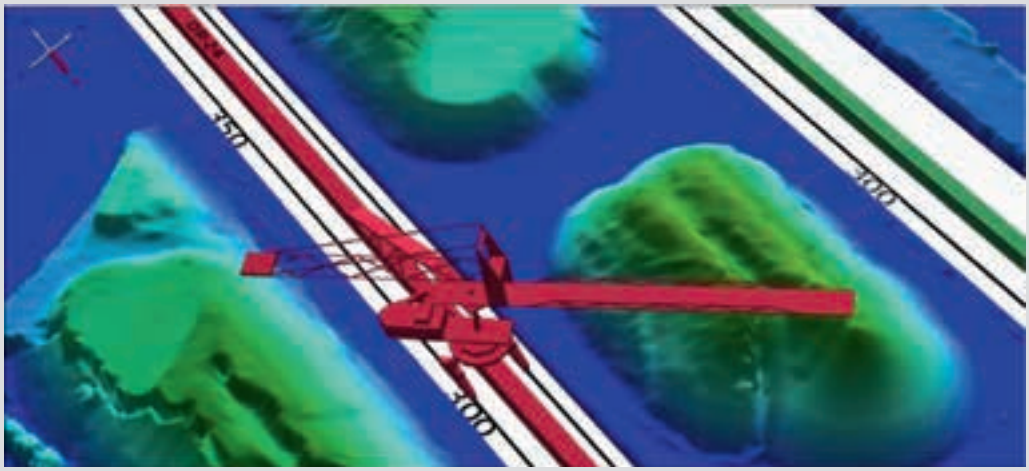
AR Speaking of planning, where does ABB's 'digital twin' fit in?

AH ABB's Stockyard Management System is, in essence, a digital twin of a stockyard. It is an evolving digital profile of the historical and current behavior of a facility and its processes that is based on massive, cumulative, real-time, real-world data measurements across an array of dimensions, all of which is designed to optimize business performance.

Data stored in different places can be referred to from one common digital twin directory to perform real-time optimization, prevent downtime and plan for the future by using simulations. While simulations are nothing new, they have historically relied on relatively small data sets or assumptions when making predictions. Digital twins, however, have access to unfathomably large data sets thanks to the Industrial Internet of Things (IIoT). They have become a business imperative in the material handling and process industries, including mining and metals.

AR Do you plan to integrate SYMS with upstream or downstream partners?

AH Yes. We develop interfaces where, for example, if there is a rail company and it needs to hand over data, SYMS can provide an interface that connects this information with any vendor. It depends on the project, but we are able to pick up this information and integrate it into the SYMS database. We recently spoke with a



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01 3D stockpile profiling and visualization, stacking process.

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02 Material tracking, showing the real-time workload of three conveyor belts, including quality grade. Green = ok; blue = better than needed; red = match not requirement.

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When it comes to dashboards and reporting, everything can be configured to meet a customer's specific needs.

European customer that operates multiple stockyards and receives data from different sources – by truck, train, and ship. Thanks to SYMS, we will be able to coordinate this data through a specialized menu that will interconnect the data from several digital logistics solutions.

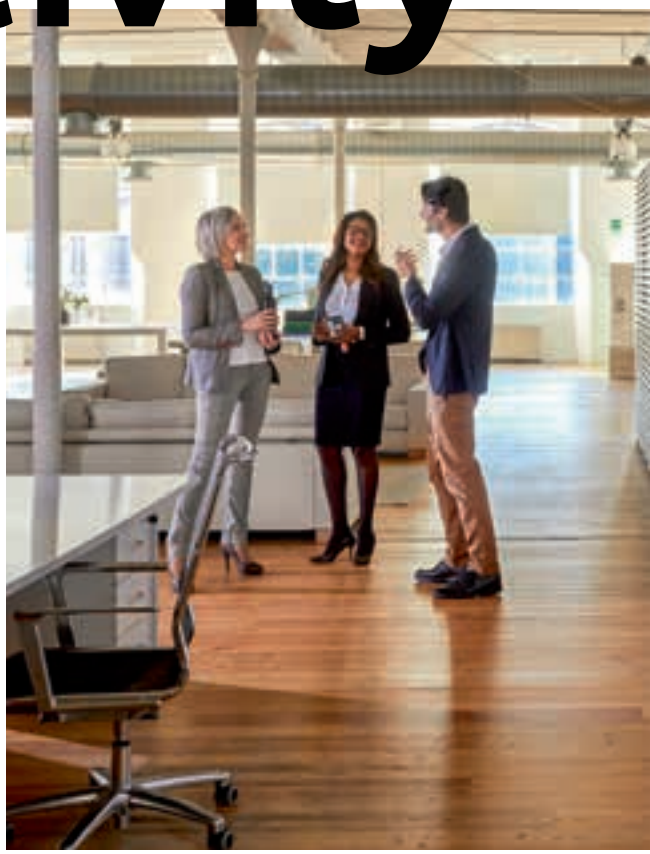
AR Let us talk for a moment about user experience and digitization. What is ABB doing to simplify the operator's job?

AH In Asia, for example, we have a customer that was, until recently, filling out nearly 2,000 pages of forms for every vessel unloaded. Now, they can do almost everything digitally. We have made a huge impact on the digitization of their day-to-day operating routines. When it comes to dashboards and reporting, we are improving everything with a view to creating a more user-friendly experience. We have improved our whole reporting system for customers. Everything can be configurated and customized to meet a customer organization's specific needs.

AR How far are we from fully autonomous operations in the mining and metals area?

AH We have one pilot stockyard that will probably enter fully autonomous operations by the end of this year. •

Efficiency & Productivity



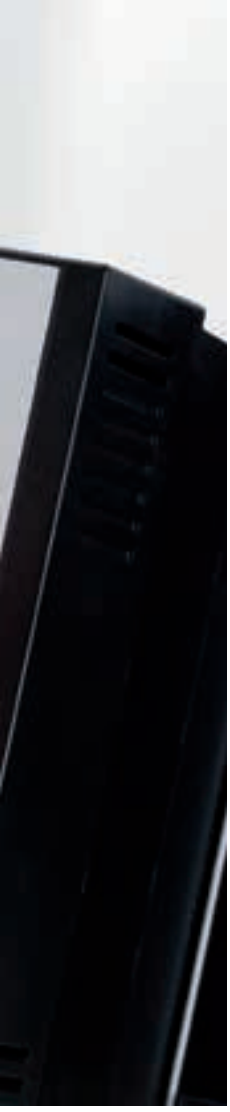
Increasingly, autonomous controls are being embedded into daily industrial and business operations. ABB combines its deep domain knowledge with its extensive experience with these rapidly evolving digital solutions to provide a sophisticated and flexible toolbox so that its customers can deliver efficiency and productivity.

60 ABB Ability™: Marking five exciting years of pushing technology boundaries
62 A home automation system designed for simplicity
66 System pro M compact® InSite for scalable energy and asset management

EFFICIENCY & PRODUCTIVITY

ABB Ability™: five years of pushing technology boundaries

In October 2021, ABB celebrates a key milestone in its innovation journey: the five-year anniversary of the launch of ABB Ability™, the company's flagship portfolio of digital solutions.



On October 4, 2016, at its Capital Markets Day, ABB introduced its portfolio of digital solutions under the banner of ABB Ability™. With an installed base of upwards of 70 million connected devices, ABB had already been working with customers in the digital space for decades. The launch of ABB Ability, bringing all these digital efforts to a single platform, was nonetheless hailed as a "quantum leap" for the company and its digital efforts. In physics, quantum leaps involve fundamental changes from one state to another, an apt analogy for what has taken place within ABB and with its customers in terms of creating value through the Industrial Internet of Things (IIoT).

The commercial launch of ABB Ability and its initial slate of solutions followed in March 2017 at ABB Customer World in Houston. At the same event, the company also announced a new strategic partnership with Microsoft to build a common cloud approach for the portfolio, based on Microsoft Azure. ABB Ability solutions blend the technology and platform-as-a-service (PaaS) capabilities of Microsoft Azure with ABB's unique domain knowledge in industrial and commercial settings to empower new insights and unlock value from the IIoT. Connecting operations from device to edge to cloud means customers can utilize system-level intelligence and improve the flexibility and sustainability of their operations.

Over the ensuing five years, ABB Ability has become an engine for digital innovation within the company, as the portfolio and its enabling technologies have reached scale. Today, ABB markets more than 200 ABB Ability digital solutions across its four business areas and the 21 divisions they comprise. Sixty percent of ABB's research and development spending and more than 4,000 software developers are dedicated to digital solutions, which together now account for roughly half of new ABB orders.

With ABB Ability, the company has expanded its range of digital partners to include some of the largest players in IT, including Ericsson, Hewlett Packard Enterprise, Huawei and IBM, giving ABB access to new digital functionalities and capabilities – 5G, edge-based data centers, cloud analytics and artificial intelligence, to name a few – and new innovation pathways to create operational insights for the thousands of enterprise customers that make use of ABB Ability™ solutions around the globe.

Behind the portfolio are a set of common enabling technologies that support ABB developers, including common application programming interfaces (APIs), containers and universal cybersecurity standards, an integrated toolbox that drives synergy and faster time to value for customers. An open, modular architecture that eschews "lock-in" and prioritizes consumption model flexibility makes it easy for customers and their IT suppliers to connect applications securely to ABB Ability™ solutions and create custom capabilities that align to an organization's unique business process needs. Dashboards and augmented technologies empower ABB customers to make sense of and act upon vast amounts of telemetry from operational technology and data stored in enterprise systems.

> It's been a great ride so far and there are a lot more pioneering innovations ahead.

It's been a great ride so far and there are a lot more pioneering innovations ahead. The 1/2022 edition of ABB Review will take a look at some of the most exciting ABB Ability solutions and how they are being deployed by customers in the real world to power better decisions throughout their business and achieve greater agility, resilience and energy efficiency. ABB Review will also be showcasing some important new research exploring the state of industrial decision-making. The 2/2022 issue will be dedicated to ABB Ability, and some of the new leaps the company is making. •

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EFFICIENCY & PRODUCTIVITY

A home automation system designed for simplicity

Demand for home automation systems is growing by leaps and bounds. However, as such systems add capabilities, they also become increasingly complex. With a view to providing the simplest and easiest-to-manage user interface, ABB has introduced a home automation system that has already won the international Red Dot Design Award for user interface design.

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01 Behind the development of ABB's enhanced UX feature is a straightforward proposition: use simplicity to hide complexity.

From luxury homes to "handyman specials," people are building and upgrading properties with home automation systems in mind. Indeed, the global market for home automation market is projected to grow from $40.8 billion in 2020 to $63.2 billion by 2025 [1]. Such systems not only provide convenience but save energy and enhance security. In addition, depending on the system, they may also result in reduced insurance costs and improved communications. Furthermore, driven by growing urbanization and increased wealth, the trend toward home automation is spreading to many developing countries.

But as such systems proliferate, consumers are demanding interfaces that are so simple as to be self-evident →01. In view of this, ABB recently introduced its latest home automation offering, the ABB-free@home® app Next →02, which is designed to control the ABB-free@home® system quickly and intuitively.

The app is the first product to be launched under ABB's new company-wide user experience (UX) guidelines for digital brand experience design. The guidelines, which benefit from user interviews and feedback, broadly define brand experience features such as information presentation, architecture, and navigation. Behind the development of the enhanced UX feature is a straightforward proposition: Use simplicity to hide complexity. The guidelines are thus designed to convey a feeling of empowerment and control to users. These objectives are supported by a standardized set of software components and pictograms that are used consistently and repetitively throughout the application with a view to creating a predictable and easy-to-understand user environment.

In designing the ABB-free@home interface designers were confronted with a unique challenge: Although the product's appearance had to comply with ABB's digital brand experience

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The world home automation market is projected to grow from $40.8 billion in 2020 to $63.2 billion by 2025.

essentials, in terms of design and implementation it also had to fit in with requirements set by Busch-Jaeger, under whose brand ABB's Home Automation offering is sold in Germany, Austria and the Netherlands. In all other countries the offering is branded as ABB.

The ABB-free@home mobile app enables users to control their home automation and accessories such as appliances, blinds, lights, lighting color, music, heating, air conditioning and scheduling. The app uses ABB's MyBuildings software to connect to the Internet, allowing users to conveniently check up on and manage their homes from anywhere by simply clicking "house

status." User experience is further enhanced by a functionality that supports all major voice control devices.

Additionally, by checking "status," users can see exactly how many lights are on, how many shutters are open, whether windows are open, and whether the alarm system has been activated. Devices can be turned on or off by simply tapping an icon. A weather icon provides information from the ABB-free@home weather station, and a "Next switching times" icon displays functions that are about to be automatically switched on or off. All such events can be suspended or rescheduled using a slider.

Navigating the app is intuitive. Users can configure the app themselves, making it easy to sort and organize devices such as blinds, lights and music by rooms, and access status messages and upcoming system actions. All devices are sorted according to their device class, such as lights, blinds, etc. Devices are also displayed according to their installation locations.

To date, more than five million ABB-free@home components have been installed in homes worldwide.

Launched in May 2020, the app has since received a Red Dot Award [2,3], a UX Design Award nomination, a German Design Award Special Mention for 2021, and, thanks to its outstanding user interface, the app is a finalist in IF Design Award 2021.

Red Dot Design Awards recognize outstanding achievements in product and communication design. This year, the Red Dot Jury's panel of international design experts placed special emphasis on revolutionary designs, highlighting design work that best demonstrates progressive interactivity.

To date, more than five million ABB-free@home® components have been installed in homes worldwide, thereby transforming conventional homes into smart buildings that are integrated with the Internet of Things. •

reddot winner 2020

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02 ABB's new app has received the Red Dot Award, which recognizes outstanding achievements in product and communication design.

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EFFICIENCY & PRODUCTIVITY

System pro M compact® InSite for scalable energy and asset management

Enabling customers to align resource utilization with sustainability targets, ABB's fully integrated system for electric power sub distribution makes seamless digital interaction, information collection and secure control possible anywhere at any time.

01 System pro M compact® InSite solution is scalable, flexible and transparent; providing advantages for public and commercial buildings from small shops to skyscrapers as described here.

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Digitization is changing the world of energy distribution; making it safer, smarter and more sustainable. Because collecting and analyzing data is now a snap, connectivity-based solutions can increase resource awareness and process behaviors. By optimizing asset management by controlling and monitoring operations and costs, a more conscious utilization of resources and energy efficiency can emerge. ABB's System pro M compact® InSite range of energy and asset management solutions for sub distribution accomplishes this by being smart and scalable, energy efficient and by enabling continuity of operation.

Scalable, flexible, transparent and compliant with energy standards, this cyber secure system collects data from devices, eg, energy- and power meters; analyzes it, and makes data available in a myriad of ways; and, at long last, allows optimization analysis and automated control

Optimizing asset management by controlling and monitoring operations and costs leads to energy efficiency.

in the field. Any size of public-, commercial- or industrial building can easily be connected to the cloud →01; the InSite Web server and existing installations can be revamped, quickly, without replacing existing components. Installation and configuration time is reduced dramatically; thereby minimizing downtime and costs.

Thanks to diagnostics and real-time notifications, total transparency over system performance is ensured. Moreover, compliance with energy efficiency standards and control over

SYSTEM PRO M COMPACT® INSITE

System pro M compact® InSite provides energy management capabilities for any size building. Existing installations of small commercial buildings like shops, hotels, offices and restaurants with few panels can be easily upgraded with plug and play assembly. By providing total transparency over the complete energy distribution system and utility consumption eg, gas and water, energy management is improved and operational costs can be significantly reduced.

Further, large commercial buildings eg, office towers, mixed-use commercial buildings, airports, shopping malls, hospitals or large hotels, can be managed more efficiently. Sub-metering and energy costs allocation of different occupiers (eg, single stores in a shopping mall) can be monitored for optimization of energy usage or maintenance processes using the local web server or cloud platform that manages the overall site.

Industrial buildings and critical power applications eg, hospitals, data centers, are assured of service continuity and predictive maintenance, particularly where it is important to reduce or prevent unplanned outages and related costs. System pro M compact® InSite solution can be seamlessly integrated in supervision systems in place for the whole facility such as Supervisory Control and Data Acquisition (SCADA) or Building Management Systems (BMS).

01

facility consumption result in energy savings of up to 20 percent – a boon to customers who aim for the highest sustainability targets.

System pro M compact® InSite
With a range of connected devices to support energy and asset management in electric distribution →02, System pro M compact® InSite can be installed as a standalone solution or integrated into any IT infrastructure, eg, cloud-based ABB Ability™ platform; making energy efficiency standards compliance easy.

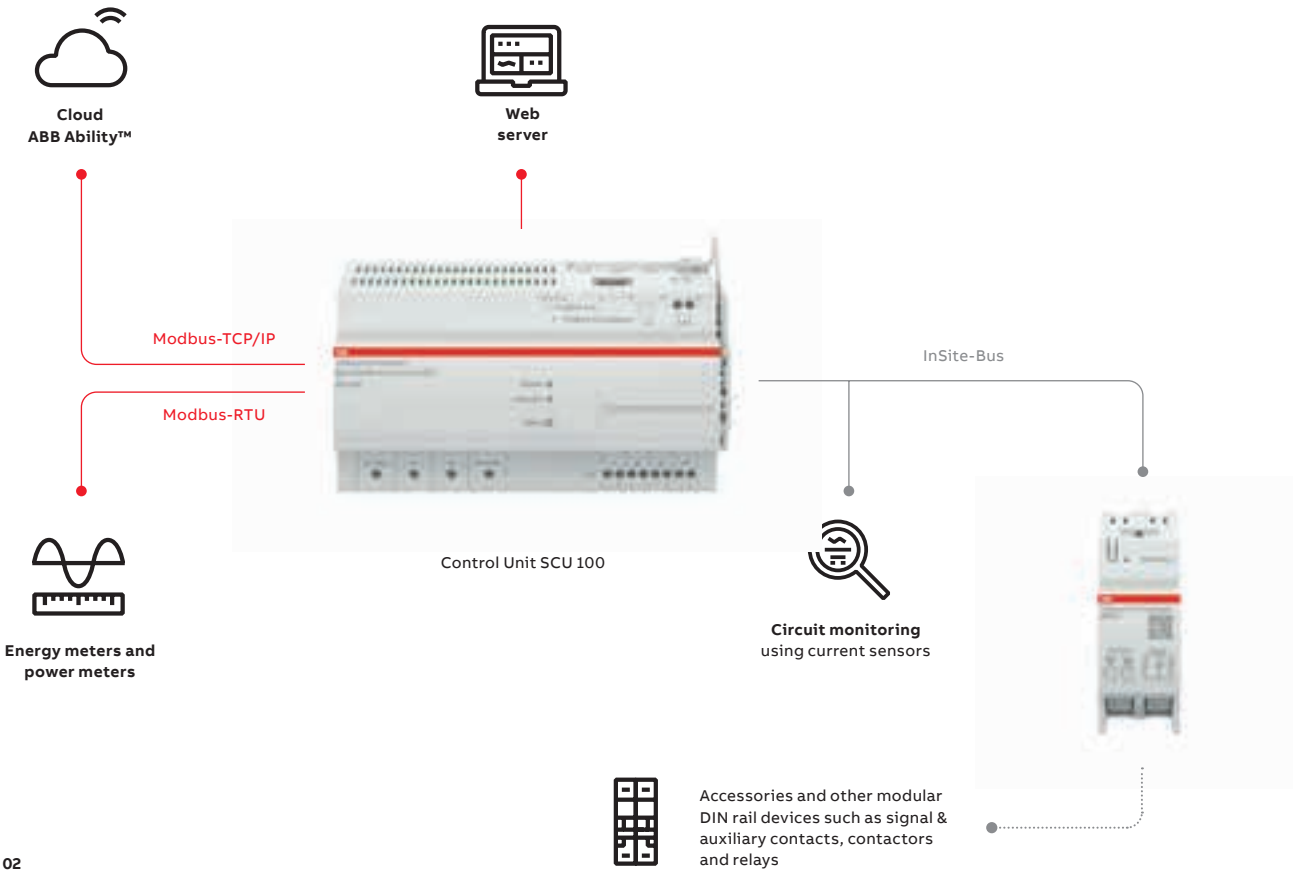
The system SCU100 control unit is key →03; it improves the electric power distribution consumption awareness by allowing better energy and asset management in sub distribution boards: data can be gathered from up to 16 energy and power meters, the system can be connected up to 96 current sensors for branch measurement, SCU100 can control the complete energy distribution system with digital input and output (I/O) modules: the interface between

DIN-rail primary equipment, protections and SCU100 control unit →02, and easily connect to classic accessories (MCBs and RCDs) and other DIN-rail products. The input module can be configured to read pulse meters →02.

Data collected by SCU100 can be displayed on any personal computer or mobile device thanks to an intuitive graphical user interface (GUI)

The modular software architecture enables effective inter-process communication, increased performance and reliability.

that supports commissioning, monitoring and controlling; making it easy to reduce energy



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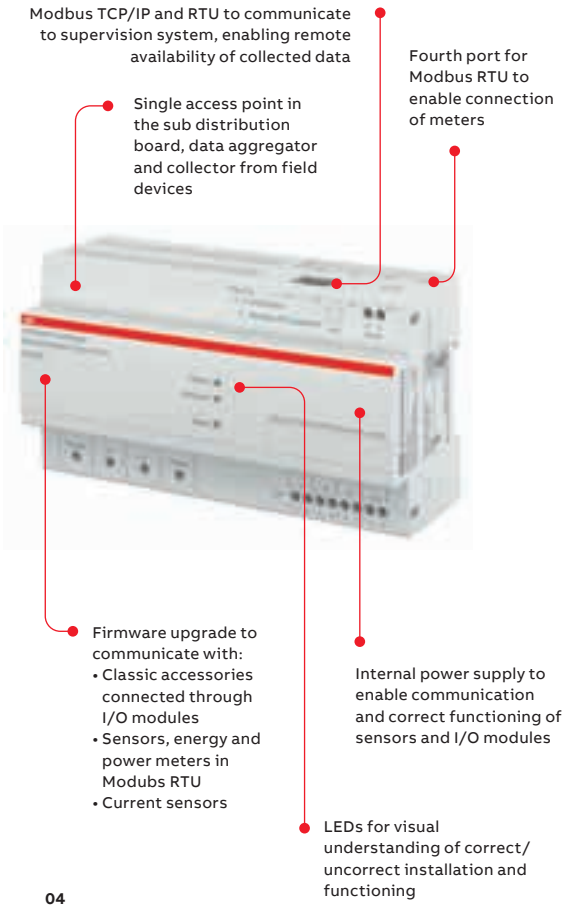

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— 02 A schematic of the System pro M compact® InSite architecture is shown.

— 03 Sample system installation is detailed that includes: the control unit, the digital I/O modules, current sensors and flat cables.

— 04 SCU100 Control unit (shown) is pivotal for the ability to monitor and control; this enables customers to implement energy strategies and reach goals.

consumption and identify potential risks. Users can customize alerts and configure automatic actions to optimize the management of energy and assets.

Monitoring and controlling is easy with SCU100 control unit

The brains of the System pro M compact® InSite range, the SCU100 control unit →04, is based on the proven CMS-700 control unit hardware with four ports for InSite bus/meters and higher CPU frequency. New system features with enhanced functions make complete in-depth monitoring

— System SCU100 control unit is key: it works to improve the electric power distribution consumption awareness.

of the electric distribution system intuitive. Moreover, SCU100 introduces support for InSite PRO-M Digital I/O modules and full preconfigured data interface for the full family of ABB energy meters (series A, B and C) and power meters (series M4M, M2M, M1M, IM300, DTDME) via a simple Modbus RTU communication protocol.

Thanks to the modular software architecture, effective inter-process communication and increased performance and reliability are possible. For instance, adding software packages does not affect the modules pre-existing on a device, thereby improving update-process efficiency which translates to less downtime because only new and updated components are distributed with an update image; the rest remains unchanged.

The operating system, based on Linux kernel, was built using Yocto Project: an open-source collaboration project that allows the creation of custom Linux-based systems regardless of hardware architecture. Here, the building of operating system, InSite software and additional open-source components is unified using recipes that describe the configuration, compilation and deployment of each component. An inhouse Python code prepares the recipes and generates output images. The built software tracks versions of software components; adding to the customer image only new or updated ones as compared to the reference supported version.

ABB relied on the user experience approach and analysis of usability heuristics to design the software WUI interface [1] →05. By applying rules, defined by Jakob Nielsen, to determine interface usability, identify issues and possible solutions, ABB ensured a superb user experience.

Defects can be recognized early and the software development process quality and product

stability can be continuously improved because the software building and testing phases are fully automated on a dedicated platform according to Continuous Integration. The platform is constructed using Docker containers, for software building, deployment and tests. Software artifacts are validated by automated tests written in Python and py.test framework. Further, system features (measurements, communication protocols and behavior of WUI) are tested iteratively, thereby guaranteeing full regression at each intermediate SW release stage until the final product is deployed. This facilitates a fast time to market and the ability to meet evolving demands.

Smarter with Input/Output modules

In addition to CMS current sensors, ABB has introduced new peripherals to handle digital Input/Output (I/O) signals and pulsed outputs for flow, heat or energy meters. This broadens the capabilities of the system to acquire more information for complete control of the sub- and final distribution cabinets and the energy consumption of connected utilities.

SCU100 provides four ports to connect up to 24 digital IOs, with four channels each. Digital IO modules are available in three variants: four Is, four Os and combined two Is/two Os.

The I/O modules architecture, based on the cost-effective and low power consuming ARM cortex M microcontroller, allows fast and reliable operation →06. Input channels can be configured

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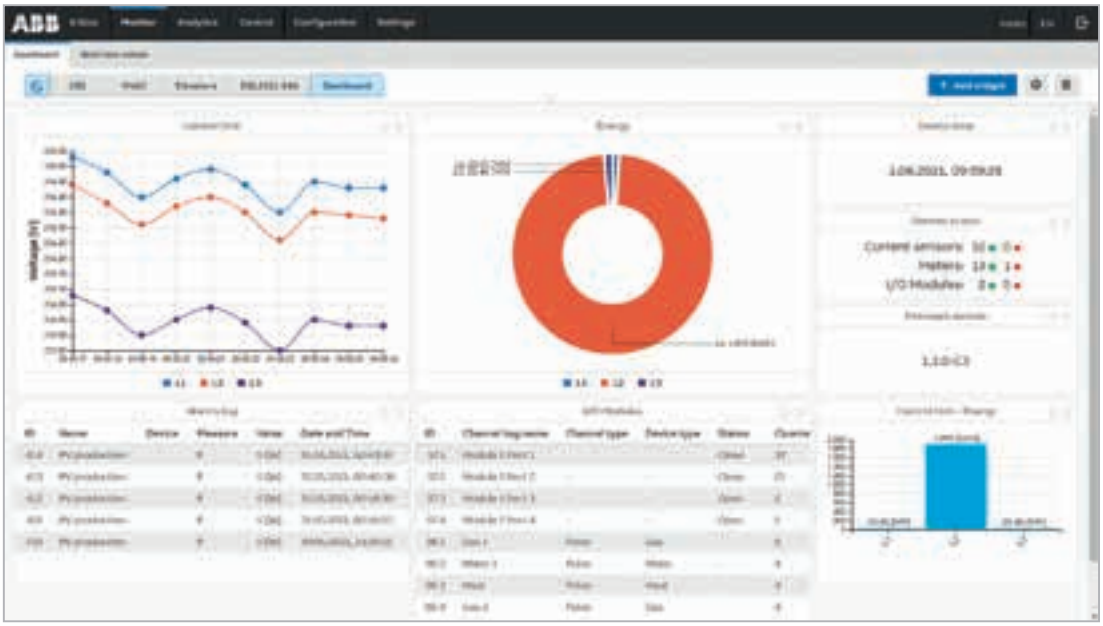
Acquiring more information for complete control is now possible thanks to the new system features.

in two modes – digital input or pulse input. Active inputs each provide 5mA of current at 24V to operate with relay-type outputs without requiring additional external power supply. Each input is galvanically isolated from the communication bus. Output channels can be programmed to



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05 An example of the SCU-100 Control Unit's WUI display is shown. Customers benefit greatly from usability.

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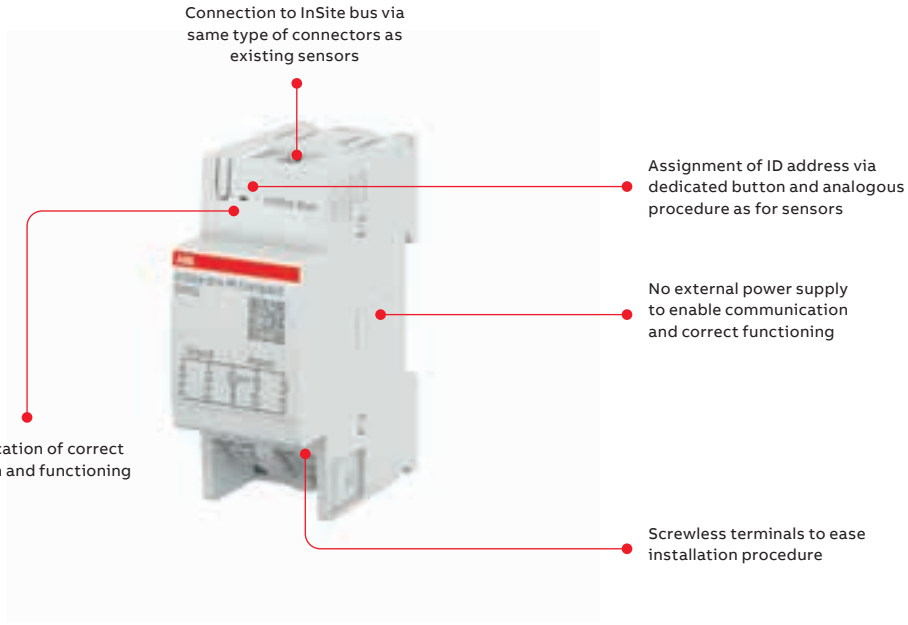
06 Connectivity and compatibility ensure fast and reliable operation with I/O modules.



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control devices, eg, motor-operated devices (ABB product ranges S2C-CM, F2C-CM and DS2C-CM) or shunt trip device for which the 2 I/ 2 O module fits perfectly. Based on dry contact, outputs require an external power supply to feed the attached accessory (24 V DC up to 230 V AC). To ensure smooth operation with other power supplies, each channel is galvanically isolated from communication bus and other channels.

Safer with cyber security

The System pro M compact ® InSite system underwent a comprehensive and rigorous cyber security assessment process: an external review of the attack surface and possible vectors that could be breached by unauthorized user access. Full system cyber security tests were performed by ABB Cyber Defense Evaluation Center (CDEC) and by ABB Device Security Assurance Center (DSAC).

Tests confirmed the robustness and resilience of SCU-100 cyber security features: packets storming on different layers, Open Systems Interconnection (OSI) model – Denial-of-Service (DoS) attacks, and known-vulnerabilities for supported communication protocols.

Additionally, Ethernet, ARP, ICMP, IP, TCP and UDP protocols have been subjected to stress tests to assess possible hidden vulnerabilities in software stacks.

And, because the SCU-100 control unit supports encrypted HTTPS and SNMPv3 protocols,, secure communication is assured. Equipped with an internal firewall based on a nftables network packet filter, the system allows only incoming and outgoing traffic on configured ports that is activated for enabled communication protocols or traffic belonging to connections initiated by the control unit eg, when connecting to the Network Time Protocol (NTP) server to update the system time. Moreover, as rules comprise rate limiter definitions, the device is protected from DoS attacks. Importantly, all invalid packages are dropped before they reach the target service and cause malfunction.

SCU-100 WUI supports authentication and authorization for three types of access roles. Harden-

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Comprehensive tests performed by ABB's CDEC and DSAC ensure that the system is cyber secure.

ing techniques, eg, limit-failed login attempts or increasing delays between attempts, discourage possible hackers from unauthorized access using brute force attacks on web application. Further protection is insured; software updates are only possible via a password protected administrator

System access point

Central Unit & Digital I/O modules
System pro M compact® InSite collects data of devices such as energy and power meters, network analyzers and protection devices that are equipped with current sensors and the integration of additional digital input and output modules.

Sub distribution board
System pro E® energy includes wall mounted and floor standing sheets steel cabinets offering protection degrees against dust and water up to IP43 and IP55 as well as a common interior fitting and busbars.

The range is simple in planning, quick in assembly and safe in application.

It allows users to build distribution panels up to 800A. With our digital platform ABB Connect Partner Hub System pro E® energy can be configured faster and with all relevant information at hand.

07

account. The customer image is delivered with included signature, which is verified on the device during update process. It ensures that no malformed, altered or virus-infected image can be installed.

Flexibility with integration into third-party cloud systems
Since the software version 1.1.0, SCU100 introduces support for REST API interface and VPN, secure connections are enhanced. It is now possible to connect multiple control units via VPN to a single access point with a customer-side VPN server. A secure virtual private tunnel can carry information between control units and a server placed in different locations.

InSite Pro M REST API gateway application is built to ease the integration of the system with a customer's cloud; including secure access to control units in the field by deploying this application into the customer's cloud platform (available on request as Docker container image). The gateway handles data retrieval from control units with RESTful pre-programmed queries and presents results in JSON format.

This integration technique has been successfully tested with ABB partners and deployed in submetering applications to gather data from photovoltaic plants and consumer communities, aggregating and storing data into third party blockchains.

More integration with ABB Ability™ Energy and Asset Manager
The InSite pro M system is now integrated into new SaaS ABB Ability™ Energy and Asset Manager →07. The connection is possible with the new E-Hub 2.0 IoT gateway or ABB Ability™ Edge Industrial gateway and the commissioning tool Ekip Connect or Ability™ Energy and Asset Manager cloud provisioning tool. The visualization of InSite data on the Energy and Asset manager cloud computing platform is possible through dedicated widgets showing collected measurement data from the InSite Pro M system. The cloud solution is suitable for small and midsize plants, shopping- or data centers, thereby saving customers up to 30 percent on their energy bills and up to 40 percent on maintenance costs [2].

Product launch and market opportunities
Launched globally in 2020, the System pro M compact® InSite range is driving ABB's energy and asset management offerings toward a more digital portfolio for sub- and final electric distribution. By introducing a fully integrated system capable of seamless digital interaction, information collection and secure control of all major electric components typically present in electric distribution, ABB is leading the way to align utilization with sustainability targets.

ABB's System pro M compact® InSite allows energy and asset management for the entire electric sub distribution.

With market recognition and success expanding, the system has been deployed in several innovative applications and configurations, eg, Blockchain solutions for residential house communities to manage measurement and billing of self-produced electricity from solar plants; data centers, in several configurations, to monitor electric performance and provide heightened security; and in Telecom for monitoring and analyzing electric consumption.

ABB's System pro M compact® InSite range offers customers scalability, flexibility and transparency and a cyber-secure standards-compliant means of energy and asset management for their entire electric sub distribution, today and in the future, thereby helping them toward a more conscious utilization of resources and energy efficiency. •

07 Sub distribution board with System pro M compact® InSite.

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01

PERPETUAL PIONEERING

Azipod® propulsion: power beneath the waves for over 20 million hours

In 1991 a marine revolution took place – quietly. ABB introduced the world of shipping to the Azipod® technology – a gearless steering propulsion system for vessels.

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Known as podded propulsion because the system relies on an electric motor, the simplest motor of all, that is housed within a pod outside a ship's hull, the system requires no oxygen to operate and generates zero exhaust. As long as electricity can be supplied the motor can be placed virtually anywhere on a ship – or in the case of Azipod® propulsion, not on the ship at all, but under →01.

Since the first cruise ship installation 25 years ago, Azipod® units have saved approximately 1,000,000 tons of fuel in the cruise segment alone, while clocking over 20 million running hours at an impressive availability rate of 99.9 percent.

Cruising through ice
An icegoing fairway support vessel in Finland became the first ship operating with Azipod® propulsion in 1991. Early trials demonstrated remarkable icegoing capabilities with Azipod® propulsion, and the images of a large tanker equipped with Azipod® propulsion "chasing its tail" in open water astounded the maritime world

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01 ABB Azipod® propulsion installed under the icebreaker Polaris.

02

and inspired the move into cruise, as well as many other vessel types.

Today, Azipod® propulsion enables vessels to navigate safely through ice up to 2.1 meters thick →02. To break ice in particularly challenging conditions, vessels powered by Azipod® propulsion navigate stern first. Propellers mill the underwater part of the ice ridge to open a passage; water flow generated by the propeller flushes the hull, allowing the ship to move ahead with ease.

In the mid-1990s, Carnival Cruise Line's Carnival Elation became the first cruise ship to be fitted with Azipod® propulsion. The system gave the ship unprecedented maneuverability, cutting the Elation's turning radius of by half, while treating passengers to the smoothest ride of their lives.

An order from Royal Caribbean International came in 1997, with three Azipod® units installed on the biggest cruise ship of its time – Voyager of the Seas. Other large cruise lines followed, selecting Azipod® propulsion for its superior performance and reliability. Space saved by locating the motor outside the ship's hull allows for more flexible design and frees up space for cabins, cargo or other features →03.

In addition to saving space on board, Azipod® propulsion also helps achieve reduced noise and vibration on board vessels – crucial for passenger and crew comfort. Passengers notice the biggest difference in confined area operations and during harbor maneuvers. This improvement in comfort is possible due to several factors, such as the absence of noise generating gears, as well as the pod motor being located completely outside the vessel's hull.

The Azipod® system can rotate 360 degrees, increasing maneuverability and allowing even the largest vessels to dock in harbors where turning circles are restricted. Crucially, Azipod® propulsion also improves operating efficiency, boosting a ship's hydrodynamic performance and cutting fuel consumption by up to 20 percent when compared with a traditional shaftline setup.

Azipod® propulsion improves operating efficiency, boosting hydrodynamic performance and cutting fuel consumption.

Due to the abovementioned features, Azipod® propulsion has rightly earned a leading position in the newbuild cruise market, powering some of the largest vessels on the water including the largest cruise ship in the world – Symphony of the Seas – which is equipped with three 20 MW Azipod® units.

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02 Azipod® propulsion enables vessels to navigate safely through ice up to 2.1 meters thick.

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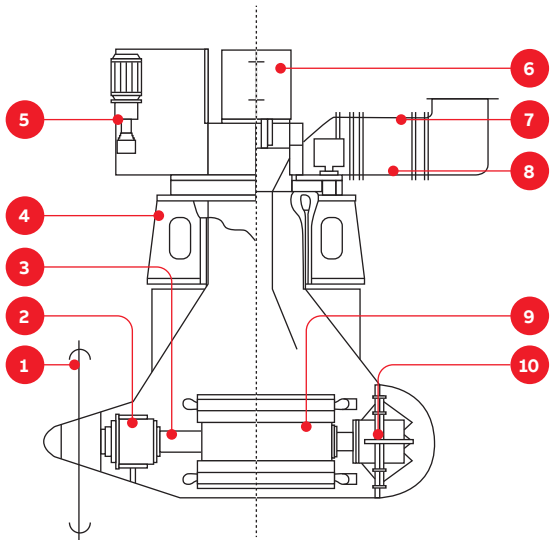
03 Main components of an Azipod® propulsion unit.



MAIN COMPONENTS OF AN AZIPOD® UNIT

1 Fixed pitch propeller
2 Bearing, shaft seals
3 Shaft line
4 Installation block
5 Hydraulic steering unit
6 Slipring unit (power/data transmission)
7 Ventilation unit
8 Air cooling
9 Electric motor
10 Bearing

IMAGINE AZIPOD®

To get an idea of the immense toughness of Azipod® propulsion, consider that it was conceived to cut through sheets of ice more than two meters thick. To understand the finesse of the system, remember that it was entrusted to move humans – the most precious of all cargoes.

The podded propulsion system relies on an AC motor (single or double wound), the simplest motor of all, requiring no oxygen to operate and generating zero exhaust. Power and thrust comes from a permanent magnet motor driven by ABB's proven water-cooled converter. Also featured is ABB's direct torque control (DTC) technology, which allows accurate control of both motor speed and torque without pulse encoder feedback from the motor shaft.

As long as electricity can be supplied, the motor can be placed virtually anywhere on a ship – or in the case of Azipod® propulsion, not on the ship at all, but under. This in turn allows the propeller to be connected directly to the motor, instead of via shaft lines or mechanical drive trains. The motor is controlled by a frequency converter, which produces full nominal torque in either direction over the entire speed range, including standstill. Over torque can also be utilized eg., in ice-going vessels.

Together, these features allow the motor and propeller to be rotated 360 degrees, pulling the ship in any direction, providing the revolutionary maneuverability that has made Azipod® propulsion a legend in the marine industry. Electrical power minimizes engine noise and vibration as well, ensuring a smoother, quieter ride. Additionally, the system's silent electric motor propulsion meets international standards for underwater radiated noise.

Safety is improved for vessels featuring Azipod® propulsion: unlike ships using a conventional shaftline system, they can be steered throughout the 'crash stop' period and take 50 percent less time to come to a complete stop.

In 2001, Compact Azipod® was launched: a version developed especially for rigs and other vessels, such as ferries. Its power range of 1 to 5 MW meets the constantly growing market demand for better maneuverability and operating economy.

Ferry nice
In 2020, ABB delivered an Azipod® propulsion system for the new Viking Line ferry Viking Glory →04. Speaking about this vessel, Jan Hanses, President and CEO, Viking Line, said that Viking Line's expectations were that she would be the most efficient cruise ferry operating in the Baltic, if not the world.

Viking Line's decision to opt for the Azipod® system came after ABB equipped a virtual model of Viking Glory with Azipod® propulsion and invited the captain to perform the run on a simulator, comparing it with a conventionally powered ferry. The captain consistently achieved a 30 minute time saving due to increased maneuverability in port. This allowed for lower speed in open water, which reduced fuel consumption on the run.

In 2020, mid-power range Azipod® propulsion was added to the portfolio. Offering power in the 7.5 to 14.5 MW range, mid-power Azipod® propulsion is tailored to provide operating benefits for owners and operators of ferries, larger offshore construction vessels, midsize cruise ships and shuttle tankers. The system is designed for low onboard height, which allows the Azipod® units to be located under the car deck of passenger and car ferries, so no deck space is taken up and vehicle movement is unhindered.

Up to 95 percent of the material used in the production of Azipod® units is recyclable.

Today, over 25 different vessel types rely on Azipod® technology – from cruise and passenger vessels to cargo ships, icebreakers and superyachts.

From factory to shipyard
Azipod® units are produced at three factories, with Helsinki and Hamina factories in Finland delivering the largest models' propulsion and steering units respectively →05, and compact units constructed at the Shanghai, China, facility, which celebrates 10 years of operation in 2021.

04

All factories stand out as models of cleanliness and safety. During production, the giant units are transported between workstations on air-cushion dollies. With the towers of the large units rising several stories into the air, the pods give the impression of weightless submarines as they glide silently across the floor.

Arriving at the shipyard fully assembled and ready for installation, an Azipod® unit is simply plugged straight into the vessel's hull. Large passenger vessels can take over two years to build – but the Azipod® propulsion system can be mechanically fitted in a matter of days. The fast installation of the units means that shipyards often install the Azipod® system just a week or two before the vessel is launched.

Future proofed from berth
Up to 95 percent of the material used in the production of Azipod® units is recyclable, testimony to the sustainable lifecycle perspective that

05

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04 Azipod® propulsion installed on the Viking Glory ferry.

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05 Azipod® propulsion factory in Helsinki Finland.

guides the development and application of this remarkable technology.

A recent independent study revealed that Azipod® propulsion for ferries could save nearly two million dollars in annual fuel costs per vessel [1]. Lower fuel consumption also means reduced CO_2 emissions of approximately 10,000 tons per ship per year, equivalent to the amount of CO_2 emitted by about 2,200 passenger cars annually.

The story of Azipod® propulsion has been written by innovative believers on a quest to deliver a new and better solution for propelling ships. The

—

Azipod® propulsion can be fitted on an existing vessel to replace the traditional shaftline system.

system's future-proof capabilities allow owners to invest today in anticipation of tomorrow's power solutions. The Azipod® system can be powered by electricity generated from any energy source, including batteries and fuel cells, and is even designed to be adaptable to energy sources that have yet to be discovered.

Azipod® propulsion is not only suitable for new ships – it can be fitted on an existing vessel to replace the traditional shaftline system. This extends the life of existing vessels, while increasing their efficiency, and allows existing resources to be utilized more effectively and for longer.

Available in the power range of 1 to 22 megawatts, Azipod® propulsion has now rounded 30 years of service to the marine industry, saving fuel and reducing emissions while delighting captains and passengers alike with smooth, precise and powerful performance. With its built-in ability to tackle new challenges as shipping sets course to a sustainable future, the next decades of Azipod® propulsion promise to be equally as rewarding. Many happy returns, Azipod® propulsion. •

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BUZZWORD DEMYSTIFYER

Autonomous shipping

As the shipping industry gears up for a future of smart, increasingly automated ships, ABB Review looks into what autonomous shipping means – and what it doesn't.

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Autonomous solutions are expected to transform international shipping in the coming decades, making day-to-day operations safer, more efficient and more productive for crews – no matter where they may be located. But what does the phrase 'autonomous shipping' really stand for?

Autonomous, not uncrewed

Perhaps the most important point to make is that in the near-term future, ships sailing themselves will remain a vision rather than reality – an autonomous ship does not mean an uncrewed one.

Autonomous shipping is set to revolutionize work in the maritime industry not by replacing humans on board vessels but by augmenting their cognitive capabilities to enhance the ship operators' potential.

As an example, the challenges are considered faced by the officer of the watch, who is responsible for ensuring a safe navigation of the vessel whilst keeping a watch on the bridge. Not only must she or he contend with working shifts and periods of fatigue and boredom, but also with spells on the bridge during which the outlook is impaired by darkness, fog or challenging weather. In such circumstances, autonomous systems supplementing a ship's radar – including cameras and sensors – could significantly improve situational awareness - easing workload, stress and strain, and enhancing safety.

The technologies exist, now the regulations are needed

The technologies for autonomous shipping are already available today for nearly any kind of vessel. For example, ABB Ability™ Marine Pilot Control, a next-generation intelligent maneuvering and control system, is designed to optimize vessel responsiveness, efficiency and safety across the entire operating profile. The system allows the deployment of joystick control for maneuvering at all times, including around the berth. It simplifies ship maneuvering by reducing the workload on automating navigational tasks and allows bridge officers to focus on the overall control and positioning of the ship.

What is still lacking, however, is the regulatory framework both at an international level through the International Maritime Organization (IMO) and, for local applications, from regional authorities. ABB is collaborating closely with key industry organizations and policy makers to support the work on defining these regulatory frameworks. It is paramount that within the industry, there is agreement on the definitions, and a solid regulatory framework is put in place to support the pace of technological development.

Towards autonomous shipping, one step at a time

The creation of autonomous shipping means starting simple and moving up the scale in a stepwise manner, to verify that each technology layer works before the next level can be tackled. As stated in ABB's B0 whitepaper, a conditionally and periodically unattended bridge would, in open water, allow the crew to manage their working hours in a different way than today.

An autonomous ship does not mean an uncrewed one.

They could avoid boredom and fatigue, and at the same time tend to other practical tasks, while autonomous systems keep the ship on course and watch for potential danger.

Manned autonomous systems could be adopted in both coastal and deep-sea trades if appropriate regulations were in place. Meanwhile the operation of tugs and service vessels could be supported remotely in a harbor, similarly to air traffic control. And fully autonomous vessels could provide transport for short-haul cargo movements or ferry crossings between two fixed points.

The future picture

The next generation of ships will be electric, digital and connected, as the industry moves towards new energy sources and increasingly autonomous ship operations. Eventually, the tasks onboard will change, but the crew and captain will still have crucial roles working alongside the technology. The future-proof ships will be built on the foundation of digitalization, and will effectively transform the industry into truly collaborative and automated operations. •

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Inspired by technology

What will the primary theme for innovation be in the years to come? Energy efficiency? Reduction in waste? What energy storage technologies will have the greatest impact? Batteries, hydrogen, or something else entirely? How will energy be converted, connected, and transformed? The next issue of ABB Review will explore some of the latest answers to such questions coming from ABB's research.

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