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THE HONG KONG INSTITUTION OF ENGINEERS GAS AND ENERGY DIVISION
INSTITUTION OF GAS ENGINEERS & MANAGERS FAR EAST DISTRICT SECTION
JOINT DELEGATION TO SHANGHAI IN 2019
TECHNICAL VISIT TO SHANGHAI ZHENHUA HEAVY INDUSTRIES CO., LTD.



Container transport is the blood of the global logistics. Millions of containers are handled at any time in all corners of the world, while ports are their focal point of transition. In ports, the containers are loaded on the ocean-goers to reach the other shore, and picked-up from the vessel and transferred to roads for arrive at their final destination. The movements of the containers in ports are labour intensive and the extensive use of diesel-driven port equipment can be polluting. Automation and electrification of container ports are promising solutions for reducing the reliance on man-power and air pollution, as well as improving safety, efficiency, productivity and hence competitiveness. China is leading container port automation, which is championed by Shanghai Zhenhua Heavy Industries Co., Ltd. (ZPMC).

Port Equipment Guru

Originated from Gongmao Shipyard in 1885, ZPMC is the China's forefront heavy-duty equipment manufacturer which products, of first export to Vancouver, Canada was recorded in 1992, are now sold to and used in 300 wharves in 101 countries. ZPMC, which major shareholder is China Communication Construction Co., Ltd. and listed in Shanghai Stock Exchange, provide physical equipment and engineering solutions in the following areas.

Large-scale Port Container and Bulk Material Handling Machineries

- Quayside container cranes
- Rubber-tyred and rail-mounted gantry cranes
- Ship loaders
- Ship unloaders
- Bucket-wheel stacker-reclaimers
- Chain-bucket ship unloaders

Offshore Engineering Equipment

- Jack-up drilling platforms
- Pipe-laying vessels
- Cable-laying vessels
- Floating cranes
- Dredgers

Heavy and Special Steel Structures

- Structural steel for the world's largest Ferris wheel in Las Vegas, Nevada, the U.S.
- Structural steel for the major bridges in China and abroad

Marine Transport and Installation

- Seven (7) semi-submersible transport vessels (the first vessel, Zhenhua 2, was launched in 1995)
- 18 various integrated transport ships

System Integration

- Integrated solution for autonomous terminals

ZPMC ten (10) production bases in Shanghai and Nantong in the nearby Jiangsu Province with total 6,670,000 square meters and 10 kilometre (km) coastline design, manufacture, supply and support 70 % of the port facilities globally. The Changxing Base in the Shanghai municipal is the largest base among all, endowed with 5 km deep water coastline, a heavy-duty dock of 3.7 km and the following floating cranes:-

Floating Crane Capacity [ton]	Quantity
1,000	1
1,300	1
1,600	2
5,000	1



Research and development (R&D) is heavily emphasised in ZPMC. Out of the 9,000 people workforce, 3,000 of them are qualified welders and 3,000 are engineers of all grades. Not only are the R&D personnel the top awarded in the entire organisation, ZPMC allocates 3 % of its annual revenue for the R&D budget and partners Shanghai Jiaotong University and tertiary educational institutions alike to supports its R&D. Innovation congress is held annually to stimulate and promote innovation and use of new technologies.

Port Automation

In ZPMC definition, port automation means the execution of the expected container port production and management tasks according to human-defined requirements with the involvement of less people by means of automatic detection, information processing, diagnosis and control, in order to release human from the heavy labour, adverse and dangerous operation environments in the container port operations.

Conventional container ports are more susceptible to the weather conditions, human errors and physical injuries, labour constraints and air pollution caused by the diesel-powered apparatuses, which result in their competitiveness compromised. Conversely, port automation may achieve round-the-clock operation and higher weather robustness, as well as higher reliability, lower safety risks due to the reduction of human-machine interfaces and less susceptible to the labour cost and actions. Not only does it offer higher competitiveness as a result, its high degree of electrification offers less emissions and hence greener environment.

Container port operations are divided into quayside operation, ground transportation and stacking operations, which each ZPMC has incorporated innovative features to achieve automation and enhance operation efficiency.

Quay Cranes

A quay crane (QC) discharges an inbound container from a vessel and ground it on a tractor's chassis, and picks-up an outbound container from a tractor's chassis and then loads onto a vessel. The conventional QC performs the container transfer between the vessel and the ground one at a time and sequentially. In case of the container is picked-up from the vessel before a tractor appears under QC, QC may have to wait until the tractor arrives and the vessel discharge may hence be halted. Likewise, should a loaded tractor be already in position whereas QC is still loading a container onto the vessel, the tractor is left idle until the spreader is vacant to pick-up the container from it.



The ZPMC solution is the two trolley spreaders and a transition bridge arrangement (Double Trolley QC). The main trolley spreader is dedicated to transfer the containers between the vessel and the transition bridge, while simultaneously and independently the intermediate trolley spreader takes care of solely the movement of the container between the transition bridge and the tractor. The arrangement splits the container transition between the vessel and the ground from one (1) step into two (2), removing the causes of idle and hence improving the productivity of vessel discharge and loading.



Container discharge from and loading on vessels retains manual command, because the ship-shore environment is currently too sophisticated for complete automation. Waves and tidal actions keep a berthed vessel and the on-board containers under constant movements, affecting the precise location of the container to be picked-up and loaded. In addition, the stowage map is often found to be inaccurate upon vessel discharge and human discernment is called to reschedule the discharge in situ. Nevertheless, leveraging the advanced cameras and sensors, the operators no longer drive QC on the crane at height whereas in a remote-control console in a room. Also, the movements of the containers between the transition bridge and the ground vehicle is relatively a more controlled environment; thus, in combination of using autonomous guide vehicles (AGV) for ground transportation, are fully automated.

The QC steel structures are fabricated and painted in the quay-side workshops with the steelwork principally supplied by Angang Steel, and QC takes its shapes by the quay. Once completed assembly, typically six (6) to 10 months after the first cut of metal, QC is loaded on ship from its assembly quay for delivery, while testing and commissioning (T&C) is performed at the site of delivery. A basic QC, which is priced at about CNY10 million, typically takes three (3) days for T&C, versus seven (7) days of T&C for a CNY20 million worth advanced automated version.

Stacker Gantries

Unlike the ship-shore transfer which is subject to many variables, container stacking is a more controlled operating environment and full automation can be attained. ZPMC utilises artificial intelligence which receives data from closed circuit television (CCTV), automatic vehicle

identification and behaviour monitor and detection to fully automate the container stacking and retrieval in the stack yards. The transmission of data is attained by 4G mobile network.

Either rubber tyred gantry cranes (RTG) or rail mounted gantry cranes (RMG), their legs normally attach to the ends of the double girder, and both the stacked containers and the tractor loading/unloading bay come under the crane span. ZPMC offers a derivative that cantilevers beyond the crane span, relocating the tractor loading/unloading bay to alongside the leg, which is also the edge of the stack yard. In doing so, all the space beneath the crane span may be used for stacking containers and hence the stack yard capacity may be increased.



The cantilevered RMG can be either one or double side cantilevered. The former type exchanges the containers with AGV on the single cantilevered side of the gantry crane. The latter type functions same as the former type on the sea-side cantilever, while its land-side cantilever exchanges the container with the external tractors.

Autonomous Ground Transportation

While the conventional container ports rely on human-driven diesel engine-powered tractors to carry the containers between the quay cranes and the stack yards, ZPMC automates and electrifies the ground movements of the containers with AGV, which first and second generation ZPMC developed in 2002 and 2009 respectively. Guided by both radio signals and fixed positioners on the ground, the driver-less AGV navigate at the precision up to 20 mm, and they recharge their batteries upon container hand-over at the stack yards.

AGV send the data from their on-board sensors to the port cloud computer for diagnosing the vehicle conditions. In case of fault appears, AGV will lock themselves at position to be subject to reset *in situ*. Should the reset be ineffective, however, they can only be towed from site. Besides, AGV relies on the block area principle to ensure clearance for safe motion.

With the above automated features implemented, ZPMC suggests, an automated container port may be 30 % more productive than its conventional equivalence. Achieving such high degree of automation, ZPMC has utilised the 4G long-term evolution telecommunication technology (LTE) for data transmission, which has resulted in the use of optic fibre has been obsolete. Furthermore, ZPMC is advancing the automation with the 5G telecommunication technologies developed by the Chinese Huawei, the Swedish Ericson and the Finnish Nokia, and ZPMC is open to the suppliers of the electrical, instrumentation and control equipment from which the port owners may choose, albeit currently Siemens is the industry preferred brand.

According to ZPMC, ZPMC has delivered the majority of the automated container ports globally to date:-

Container Port	Asia	Australasia	Europe	North American
Fully Automated	4	2	5	1
Semi-Automated	18	3	9	5
ZPMC Delivered	17	1	12	5

Port Automated Showcase

Since the first delivery of automated quay cranes to European Container Terminals in Rotterdam, the Netherlands, in 1998, ZPMC has continuously evolved its technologies and solutions for the automated container terminals. Shanghai Yangshan Port Phase 4 (YP4) is the ZPMC latest show-case of total automated container port solutions.

Showcase Timeline

The YP4 construction commenced in December 2014 and commissioning began in 2017. Operational in 2018, YP4 is the world's largest single fully automated container, which seven (7) berthing ports along the 2,350 m long quay and 61 stack yards can deliver the design annual throughput of 6.3 million twenty-foot equivalent units (TEU). YP4 is equipped with and ZPMC has delivered the following automated facilities in the first three (3) batches:-

Equipment	YP4 Required	ZPMC Supplied
Double Trolley QC	26 (double container spreader on main trolley)	16
Portal Slewing Crane	-	1
Non-cantilevered RMG	-	60
Cantilevered RMG	120 (26 single cantilevered and 2 double cantilevered)	28
RTG	-	4
AGV	130 [with two (2) charging stations]	80

The contract for the Double Trolley QC and RMG was signed in July 2015, and AGV in December 2015. By May 2016, the first batch of three (3) QC was delivered, while the first batch of 10 AGV and RMG arrived at site in end June and mid-July of the same year respectively. In December 2016, mock operations conducted with three (3) QC, 15 AGV and five (5) blocks achieved 15 cycles per hour. The first batch of the equipment was commissioned 12 months after contract award.

Stepping into 2017, with more QC and AVC were delivered, the commissioning of the initial stage equipment accelerated and by September of the year, 10 QC, 50 AGV and 19 blocks were trailed round the clock with a 5,000 TEU container vessel. On the YP4 commercial operation date of 10/12/2017, the daily throughput of 5,855 TEU grossly surpassed the manual operated record, while a year later in 2018, the two (2) million TEU annual throughput was achieved.

Following the triumph of the first batch, ZPMC delivered and commissioned 28 cantilevered RMG, four (4) RTG and one (1) portal slewing crane in the second batch, as well as two (2) Double Trolley QC with double container spreaders, four (4) Double Trolley QC with single container spreaders, 30 RMG and 30 AGV in the third batch. All the facilities in the second and third batch have been delivered in 2018, and ZPMC completed its YP4 contract within three (3) years.

Meanwhile, ZPMC is tendering for the supply of the fourth batch of facilities, comprising five (5) Double Trolley QC with double container spreaders, eight (8) single cantilevered RMG, 12 double cantilevered RMG and 30 AGV, which delivery is to be made in 2020.

Showcase Technology

The sea-side RMGs in YP4, which exchange the containers in the stack yards with the internal tractors and AGV, are the world's first of their kind to receive a 61 ton double 20 TEU spreader. The land-side RMGs, which transfer the containers between the stack yards and the external tractors, attain automated unloading of the containers on the external tractors. Both sea-side and land-side RMGs achieve high productivity and efficiency, as well as requiring less site operating personnel.

Each AGV in YP4, powered by integrated high efficient lithium ion battery and air-conditioning module, can carry two (2) 20 feet containers for exchange at the sea-side RMG. After fully automatic robot-executed battery swap in the dedicated workshop, which can complete within six (6) minutes, a fully charged AGV can operate continuously for eight (8) hours. AGV relies on its on-board laser detectors, radio and location antennas, speedometer, steering meter and gyroscope to provide signals to the navigation controller, which commands the vehicle to manoeuvre inside YP4.

Leveraging the benefits of stable and high bandwidth, high spectrum efficiency, low latency, strong anti-interference ability and network redundancy with double coverage, LTE is utilised for the communication between the modularised and distributed AGV fleet management system and maximum 150 AGVs operating simultaneously. The large scale AGV fleet management system not only does optimise the AGV routes, it also co-ordinates the operations of all gantry cranes, the fully automated AGV battery swaps, spreader transfer and others. All the activities commanded by the AGV fleet management system can be real time displayed in the graphical user interface in the control centre.

YP4 advanced automation is attained by the terminal operation system which automatically schedules the stagger of the containers in the stack yards according to the containers' weight. It also makes good use of "big data" and cloud computing technologies to collect the vast amount of raw operating data for off-site equipment condition diagnosis.

Based upon the YP4 success, ZPMC is improving the technologies for QC, RMG and AGV:-

- Big data-based remote QC full cycle health diagnosis, forecast and assessment, such as the monitoring of the QC steel structure and the collection of key lifting operation data;
- Two container spreader for the intermediate trolley on QC;
- Spreader orientation monitoring and trolley active anti-roll on RMG with the lifting cable of longer life;
- Pass through layout battery swapping station for AGV for the maximised battery storage space and AGV movement efficiency

Remarks

ZPMC is the number one port equipment solution provider in the world and an excellent role model of continuously adding value to the conventional products. It effectively transforms the ordinary and individual heavy lifting apparatus into an integrated and intelligent goods movement system. Container ports used to be polluting, highly labour-intensive and weather-sensitive; now ZPMC can turn them into an environmentally clean, labour-lean and weather-robust business. Not only is the ZPMC unparalleled manufacturing capacity exhibited, its outstanding system development and integration capabilities are well presented to the privileged members of Institution of Mechanical Engineers Hong Kong Branch (IMechE-HKB), The Hong Kong Institution of Engineers Gas and Energy Division (HKIE-G&E) and Institution of Gas Engineers & Managers Far East District Section (IGEM-FEDS) in their visit to ZPMC on 5/6/2019.

IMechE-HKB, HKIE-G&E and IGEM-FEDS thank ZPMC for its hospitality in receiving the delegation.

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