Macau Light Rapid Transit (MLRT) : Mainstay transport system for a world-leading tourist city

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The Macau Special Administrative Region (Macau) facing the South China Sea consists of the Macau Peninsula, which borders China, and a unified island formed by reclaimed land that connects Taipa and Coloane islands. The area developed from land reclamation is called Cotai. The peninsula and the island are connected by three bridges. Macau is densely packed with hotels and modern architecture, as well as buildings from the Portuguese colonial era. With a population of approximately 680,000 (in 2019), Macau has the highest population density in the world. Its casinos, a number of world cultural heritage sites and the Macau Grand Prix street circuit racing event have made Macau one of the world's leading tourist destinations. The number of tourists visiting Macau reached 39.4 million in 2019.

Macau does not have rail-based transportation. Since buses and taxis are the daily means of transportation, traffic jams and environmental pollution are becoming major concerns. The Macau government began researching countermeasures in 2002 aimed at solving the urban traffic concerns. In 2011, Mitsubishi Heavy Industries Engineering, Ltd. (MHIENG) was awarded an order for the rolling stock and related systems of the Macau Light Rapid Transit (MLRT). The following is an overview of the rolling stock and related systems of the MLRT Taipa Line, which started operation in December 2019.

1. Overview of the MLRT System

The MLRT system is an Automated Guideway Transit (AGT) that uses fully-automatic unmanned vehicles, known as Crystal Mover (brand name), with rubber tires.

Due to the characteristics of the city, the line wound through a group of residential areas and resort hotels, and the AGT system of our company, which is quiet and has a short turn radius, was adopted. The system is also helping to alleviate the chronic traffic jams in Macau.

The MLRT is a fully-automated, driverless medium-capacity passenger transportation system. It is comprised of the following subsystems: rolling stock and dedicated guideway tracks, automatic train control (ATC) signaling system, power supply system, Supervisory Control and Data Acquisition (SCADA) and other communication systems, platform screen doors, operation control center and backup control center and automatic fare collection, as well as maintenance equipment and facilities at the depot. The number of passengers per hour per direction (PPHPD) of the MLRT at peak hours is 4,760. The trainset configuration can be expanded from a 2-car single unit train (SUT) to a 4-car double unit train (DUT), and transport capacity can also be hiked by increasing the number of trains.

Maintenance is carried out at the maintenance and stabling facility at the depot (**Figure 1**). The operation control center (OCC) controls and monitors the functions of the entire system (**Figure 2**). Currently, the MLRT depot has 110 vehicles but the train storage capacity of the depot can be increased for future line extensions.

Figure 1 Depot

Figure 2 Operation Control Center

2. Features of AGT system components

2.1 Route/Track

The MLRT Taipa Line, which started operation in 2019, is 9.3 km in length and has 11 stations. It connects tourist access points, such as the airport and ferry terminal, resort hotels and residential areas (**Figure 3**). It is a double-track line made of concrete guideways (**Figure 4**). The maximum route gradient is about 60 ‰ and the minimum curve radius is about 45 m on the main line and about 30 m on the depot line. Steel guide rails are installed on both sides of the track for guiding the vehicles. Emergency walkways are installed across the entire line to secure an evacuation passage from a disabled vehicle to the nearest station.

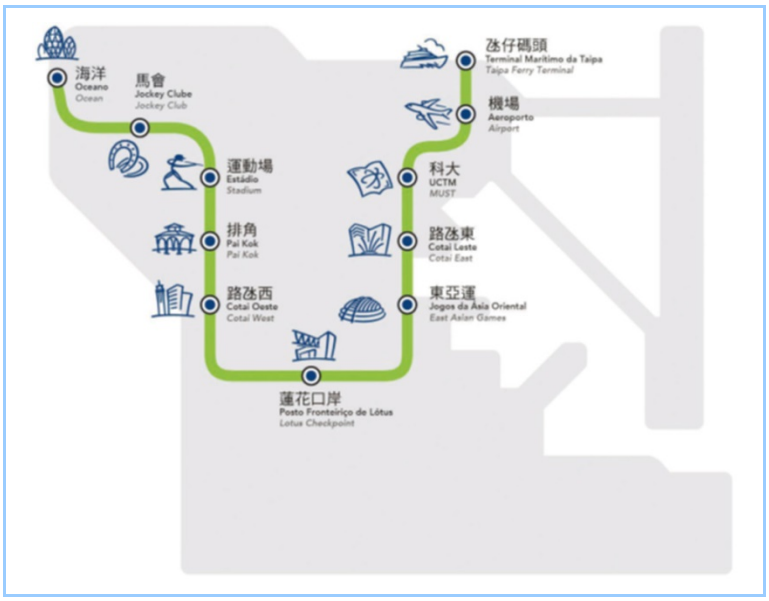

Figure 3 Route Map

Figure 4 Macau LRT Double Tracked (Up and Down Track) Guideway

2.2 Operation

The approximately 9.3 km commercial route connects 11 stations by double tracks. Multiple fully-automated, driverless single unit trains (2-car configuration) can circulate in a pinched loop operation inside the double-track section at headways between 3 minutes (in peak hours) to 5

minutes (in off peak hours), 19 hours a day, 365 days a year. A one-way trip takes about 23 minutes.

During the morning and evening peak hours, additional trains can be put into service on the main line to reduce the headways between trains. Furthermore, 2-car single unit trains (SUT) can be coupled to form a 4-car double unit train (DUT) to increase transport capacity. The MLRT system is also designed for bidirectional train operation throughout the line. Its highly-flexible operation modes include single-track shuttle operation, double-track shuttle operation and partial single-track operation by using crossovers located over the route.

2.3 Rolling Stock

The train has a fixed two-car configuration. Each car is 11,750 mm in length, 2,795 mm in width and 3,795 mm in height. The total length of the trainset is 23.5 m. The passenger capacity per car is 119 people (6 standing passengers per square meter and 22 seated passengers, at a crush load of AW3). The average operating speed is 30 km/h and the maximum operating speed is 80 km/h. The car body has an aluminum alloy double-skin structure, making it lightweight and energy efficient. The specially-designed large front windows allow passengers to enjoy a panoramic view from the interior, creating a feeling of openness in the passenger cabin (**Figure 5**). High-definition LCD displays are installed above the four doors and at the two ends of each car to provide passenger information such as route maps and other general information.

Waves of orange accents are drawn on both sides of the vehicle exterior on an aquatic white and deep-sea blue background. The design, called “Ocean Cruiser,” was chosen by local residents based on the concept that Macau is a seaside resort city. Two trainsets can be coupled into a 4-car configuration for operation during periods of high passenger demand (**Figure 6**). All bogies are steering bogies. Since the guide wheels follow the guide rails on the tracks to steer the bogies, it is not necessary to switch the steering mechanically in the direction of travel. The rubber tires produce minimal noise and little vibration during operation. The tires are fitted with air pressure sensors to monitor constantly for any abnormalities in the air pressure.

Figure 5 Rolling Stock Interior

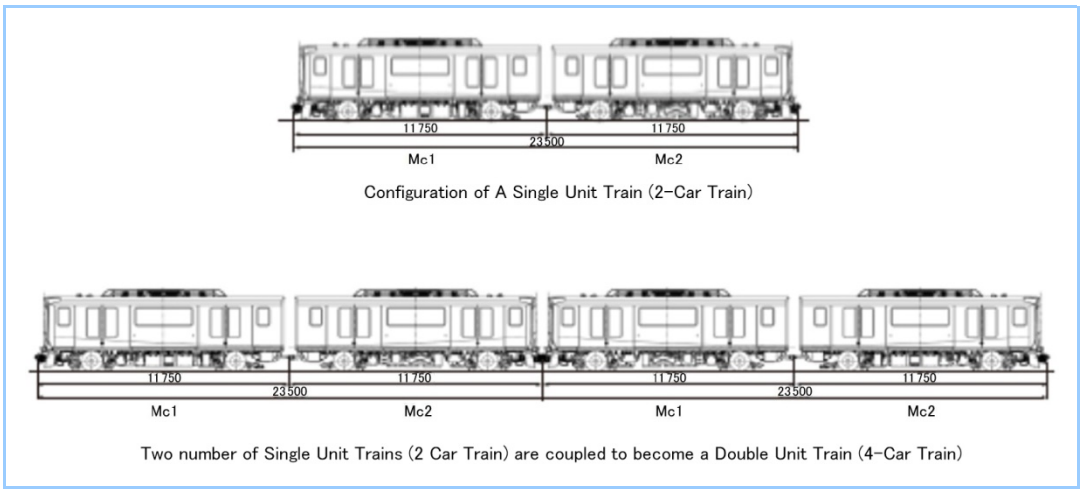

Figure 6 Train organization diagram

2.4 Automatic Train Control System

Together with an integrated wireless communication system, a Communications-Based Train Control (CBTC) system is used for the signaling system. Wireless communication between the

wayside and the trains enables the continuous two-way transmission of train control information and status data. The use of leaky coaxial (LCX) cables for the communication system enhances transmission stability. This wireless communications network features redundant systems on both the wayside and the train side to ensure high reliability.

The onboard signaling equipment determines the absolute position of the train or its distance from a base point via an on-board receiving device when the train passes a wayside coil. The train position is calculated by measuring the number of axle rotations as the distance travelled by the train in the section between the two wayside coils. Since the signaling system is able to specify the vehicle's position with a high degree of accuracy, high-frequency operation and fine adjustments in acceleration and deceleration can be made by specifying the speed limitation commands according to the vehicle's position on the tracks (**Figures 7**, **8**).

Figure 7 Wayside Signal and Turnout

Figure 8 Signal Equipment Room

While speed sensors and wayside coils are used to calculate the train's position, continuous two-way wireless communication between the wayside and the train allows changes in status such as the vehicle's operating route and mode of operation based on the train position on the track even when the train is traveling between stations. For this reason, the operation is more flexible than conventional systems.

2.5 Communication System

The ground communication system consists of various subsystems connected by a network, including the main transmission system, public address system, passenger information display system, surveillance cameras (CCTV) and telephones.

The onboard communication system uses space wave wireless communication. It utilizes dedicated frequency bands for data transmission and voice communication between the train and the wayside. Image data is transmitted via wireless signals from the onboard CCTV system that monitors the vehicle interiors.

LCD displays are mounted on station platforms and onboard trains to provide information to passengers. Together with public address announcements, the display system provides train operation information and gives alerts to passengers. It is also used for providing train arrival time, promotional information, emergency messages and other important notifications (**Figure 9**).

Figure 9 Passenger Information display at platform

Figure 10 Power Distribution Equipment Room

2.6 Power Supply System

The MLRT receives 22 kV three-phase AC power from two substations via two power lines. One substation is located near the maintenance depot and the other is located near the terminal station of the MLRT main line. The 22 kV AC power is converted to 750 V DC at the substations and supplied to the power lines along the guideway tracks for train operation. The 22 kV AC power is also stepped down to 400 V AC and distributed via an uninterruptible power supply (UPS) for the signaling, communication and other equipment. The entire system is powered via two substations and either substation can provide sufficient power.

Redundancy is also built into the two substations so train operation will not be affected if the power supply from one substation is temporarily interrupted or if the power equipment is under partial maintenance and malfunctions. The power line is sectioned according to the patterns of train operation to provide a high degree of flexibility in supplying or shutting off power. The load break switches installed between sections can be opened and shut off power to individual sections for maintenance and in response to malfunctions (**Figure 10**).

Regenerative Energy Storage Systems are provided at each station and connected to the traction power circuits. When an arriving train approaching a station decelerates by using regenerative braking, the energy fed back to the traction power supply system will be stored in the batteries. When a train departing from a station accelerates, the energy stored in the batteries will be utilized accordingly.

All electrical equipment is connected to the dedicated Supervisory Control and Data Acquisition (SCADA) system at the OCC, which monitors the charged condition and status of the power supply equipment, and switches the power supply on/off.

2.7 Station Facilities

Platforms are fitted with platform screen doors to prevent passengers from falling onto the tracks. Half-height platform doors are installed at elevated platforms. By minimizing the gap between the vehicle and the edge of the platform, passengers can get on and off the train safely. If a train arriving at a station exceeds the designated stop area and stops at a position not aligned with the platform door, passengers can disembark using the emergency escape door on the platform (**Figure 11**).

If an emergency such as a breakdown or an accident occurs and the train stops in-between two stations, passengers can follow onboard instructions from the OCC to open the train doors manually with the emergency door handle and use the emergency walkway on the track to evacuate to the nearest station. Since the train is stopped in an emergency, the power supply will also shut down automatically.

2.8 Automatic Fare Collection (AFC) System

The AFC system consists of the central control server, integrated with automatic gates and ticket vending machines being installed at every station. The central control server has functions for adjusting fares, managing IC cards, calculating sales revenue and submitting a Consolidated Report. MLRT uses a contactless IC card, which can be replenished (**Figure 12**).

Figure 11 Platform Screen Door

Figure 12 Automatic Gate

3. Conclusion

The Macau LRT has been used by 27,000 people per day for one month since opening on December 10, 2019, far exceeding the expected 20,000 people per day. This has contributed to the improvement of the mobility of residents and tourists, and has already become established as a means of urban transportation. It is also expected that this system will reduce the environmental load (CO_2 reduction) by alleviating congestion in urban areas. In view of these advantages, the Macau government is planning to extend the system on several routes, and it is expected to become an increasingly important means of transportation in cities (**Figure 13**).

Figure 13 Passengers on a Platform

AGT systems are a new type of fully-automated transport system with electric power drives, utilizing rubber tires to provide a smooth ride with low noise. MHI Group's AGT systems are currently in operation at several airports in the United States, including Miami, Washington D.C., Dallas, Atlanta, Orlando and Dallas, and are highly regarded for their high operation rate stemming from high-quality O&M (operations and maintenance) services. These systems also have an extensive track record of positive performance around the world, including in Singapore, South Korea and Germany, in addition to Japan. They are in a position to compete for the lead in the market for new transport systems in Japan and overseas.

MHIENG will utilize the strengths of its AGT system, including the reliability demonstrated by previous projects and its operational track records, as well as the engineering and project management capabilities acquired from this extensive experience, to pursue initiatives for new construction, the expansion of existing routes, enhancing transport capacity and carrying out renovation projects, further focusing on the widespread adoption of AGT systems.