Research on the Power Batteries for the Sutong GIL Special Transportation Vehicle

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Abstract: The GIL Special Transportation vehicle (GIL) is a special device to transport the GIL unit equipments for the GIL project. Due to the complicated environment and massiveness of Sutong tunnel, combined with the large weight of the GIL unit, the power system for the GIL transportation vehicle is crucial for the completing of GIL project. In this paper, we discuss the generally used power systems for the transportation vehicles in terms of safty, reliability, capacity, and effectiveness, etc. By analyzing the power requirement of Sutong GIL special transportation vehicle according to the environment of the Sutong tunnel and the weight of GIL unit equipment, we choose the lithium iron phosphate power batteries for the Sutong GIL special Transportation Vehicle combining with the features of these power batteries, which helps the Sutong GIL project to finish within the schedule.

1. Introduction
Cross Yangtze River, there is a huge bridge called Su-Tong Yangtze River Highway Bridge (Su Tong Bridge) which connects Suzhou city and Nantong city in Jiangsu Province. It is one of the largest and most complicated extra-large bridge project in China, with total length of 32.4km consisting of three main parts, the viaducts on both banks of the river and the central part over the water. The entrant part over the water is about 6km long [1].

Beside this splendid Su-Tong Bridge, there is an Ultra High Voltage gas-insulated line (GIL) for the Sutong Underground Tunnel located one kilometer upstream of the Sutong Bridge. This project has the highest voltage level(1100KV), and the largest transmission capacity in the world [2]. Currently it is the deepest buried tunnel in China and the highest soil and water pressure tunnel project, with a line length of about 5.4Km as in Fig.1. The total length is approximately 7.431 Km.

Fig. 1. Ultra High Voltage 1100KV gas-insulated line (GIL) for the Cross Yangtze River Sutong Underground Tunnel Project [2]

During the construction of GIL project, there are about 2000 GIL unit equipments to be transported from the south bank Suzhou city or the north bank Nantong city along the tunnel. Each GIL unit is about 18m in length, and is very heavy. For example, one unique unit is about 5.1 tons, and the three-phase
transport unit is about 13 tons. In the tunnel, due to the space limit, how to transform these huge and heavy GIL equipments becomes one of the challenges.

To transport these GIL equipments in the Sutong tunnel, the special transportation vehicle should be reliable. As in Fig.1 the GIL tunnel has the features of long-distance, large-slope, and various radiuses, etc. In addition, the installation of GIL unit equipments has the characters of heavy weight, high load, and precise positioning, etc. Considering these constraints, the special transportation vehicle for GIL equipments is chosen to power with the battery system in steady of the traditional internal-combustion engine. Fig.2 depicts the model of vehicle. From it, we note the vehicle includes two cars. In these two cars there are eight kinds of components. The table left to Fig.2 lists these eight kinds of components. We note that in each car, there is one battery system. Herein the battery system should be powerful enough to support the weight of the GIL unit. It adds much challenge to usage of the battery system.

![Fig.2. Special Vehicle for Transportation of Sutong GIL Equipments](image)

2. Discussion of Power Batteries

At present, the power batteries can be classified into three classes: lead-acid batteries, nickel-metal hydride batteries (Ni-MH), and lithium-ion batteries. Now we analyze the features of these power batteries.

2.1. Lead-acid battery

In the lead-acid battery, the electrode is mainly made of lead and its oxides, and the electrolyte is a sulfuric acid solution. In the discharging status, the main component of the positive electrode is lead dioxide, while the main component of the negative electrode is lead. In the charging status, the main components of the both positive and negative electrodes are lead sulfate.

Compared to other storage batteries, the lead-acid battery is earliest industrialized. It dominated the chemical battery market, and has been widely used. As it has been industrialized for long time, the technology is most mature. It has the features such as low cost, non-flammable, stable, reliable, and good applicability.

However, the energy density of lead-acid battery is relatively low, e.g. 30–40Wh/kg, which is about 1/3 of the lithium-ion battery, and 1/2 of the hydrogen-nickel batteries. And its cycle life is short. Theoretically the cycle times of the lead-acid battery is about 1/3 of the lithium ion battery [3].

2.2. Ni-MH battery

Ni-MH batteries are of good performance. They are divided into high-voltage and low-voltage. The positive electrode active material of nickel-metal hydride battery is Ni (OH) 2 (called NiO electrode), and the negative electrode active material is metal hydride, which is also called hydrogen storage alloy (electrode called hydrogen storage electrode). The electrolyte of Ni-MH battery is a 6mol/L potassium hydroxide solution. Ni-MH batteries are currently used in storage batteries for the hybrid vehicles. As an important aspect of hydrogen energy application, nickel-metal hydride batteries have attracted more and more attentions [4].
Compared with lead-acid batteries, the energy density of Ni-MH batteries is about 70-100Wh/kg. It has the features of high power density, high current discharge, and good performance of low-temperature discharging. However, the voltage of Ni-MH cell battery is 1.2V, which is 1/3 of lithium battery, the volume of the batteries pack is larger than that of lithium battery with the same requirement.

Like lithium batteries, Ni-MH batteries also require a battery management system, which concerns on the management of charging and discharging. This is due to the "memory effect" of Ni-MH batteries, i.e., the capacity of the battery will decline during the procedure of cyclic charging and discharging. The overcharging or discharging might aggravate the capacity loss of Ni-MH batteries, while for lithium batteries the capacity loss is nearly negligible. Therefore, for manufacturers, the Ni-MH battery control system will avoid overcharging and discharging. For example, the charging and discharging area of Ni-MH battery is set to the certain percentage of the capacity so as to slow down the capacity dropping rate.

2.3. Lithium-ion Battery

Lithium-ion batteries are organic electrolyte batteries which use lithium compounds such as lithium manganate, lithium phosphate, or lithium cobaltate as the positive electrode, and lithium-ion-containing carbon materials as the negative electrode. Currently, for pure electric vehicles, the energy storage devices usually use lithium-ion batteries [5].

According to the materials of lithium-ion battery cathodes, the automotive power lithium-ion batteries can be divided into: lithium manganate batteries, lithium iron phosphate batteries, lithium cobaltate batteries, ternary polymer lithium-ion batteries. We will introduce them in the following section.

2.3.1. Lithium Manganate Battery. The Lithium manganate battery uses lithium manganate as the positive electrode material. Its nominal voltage reaches 3.7V, which is widely used because of its low cost and feature of safety. Lithium manganate (LiMn2O4) has a spinel structure. Its theoretical capacity is 148mAh/g, and the actual capacity is 90~120mAh/g. The operating voltage range is 3~4V.

The advantages of Lithium manganate battery include rich manganese resources, cheap price, high safety, and easier preparation. The disadvantage is that the theoretical capacity is not high. And the material will slowly dissolve in the electrolyte, i.e. the compatibility with the electrolyte is not good. During the procedure of deep charging and discharging, the material is prone to lattice distortion, which causes the battery capacity to drop rapidly, especially in the scenario with high temperature.

2.3.2. Lithium Iron Phosphate Battery. The lithium iron phosphate battery uses lithium iron phosphate (LiFeO4) as a positive electrode material. LiFeO4 has an olivine crystal structure, and its theoretical capacity is 170 mAh/g. In fact, the capacity can reach 110 mAh/g without modification. By surface modification of lithium iron phosphate, the actual capacity can reach 165mAh/g (close to the theoretical capacity), and the operating voltage is about 3.4V.

Lithium iron phosphate has the characteristics of high stability, safety, reliability, environmental protection and low price. However, its disadvantages are large resistivity, low utilization of electrode materials, and severe degradation of low temperature performance.

2.3.3. Lithium Cobaltate Battery. The lithium cobaltate battery uses lithium cobaltate(LiCoO2) as a positive electrode material. Its nominal voltage is 3.6V. LiCoO2 has a spinel structure and its theoretical capacity is 135~145mAh/g.

The advantages of lithium cobaltate battery are superior electrochemical performance, easily processing, stable performance, good consistency, high specific capacity, and outstanding comprehensive performance.

However, the application of lithium cobaltate batteries is relatively small. The technology of cobalt lithium for small batteries is very mature, and it is difficult to apply for power system. The biggest disadvantage is that cobalt is a relatively scarce strategic metal. Therein the cost of lithium cobaltate batteries is very high.
2.3.4. Ternary polymer lithium ion battery. The ternary polymer lithium ion battery uses a ternary cathode material of lithium nickel cobalt manganese (Li (NiCoMn) O2) or lithium nickel cobalt aluminate [6]. Its capacity is about 160~185mAh/g. The voltage high line can reach 4.2V, and the discharge platform can reach 3.6~3.7V.

Compared with lithium iron phosphate batteries, ternary polymer batteries have the advantages of high voltage platform, higher capacity density, low temperature resistance, and better cycle performance. But ternary polymer batteries also have their own disadvantages, such as poor safety, poor thermal stability. It will decompose at temperature of 250-300°C, and the chemical reaction of ternary lithium materials is particularly strong. Once oxygen molecules are released, the electrolyte quickly burns under the action of high temperature, and then deflagration occurs. When the ternary polymer battery is charged and discharged with big rate, the positive and negative electrodes undergo volume shrinkage and expansion during the charging and discharging procedure. The larger the charge and discharge current is, the more severe the contraction and expansion will be. Therein the particles of the positive and negative electrodes are easy to explode or flee from the current collector during the rapidly changing of the volume, which results in the fast decay and the loss of capacity.

3. Batteries Consideration for Sutong GIL Vehicle

3.1. The Characteristic of Sutong GIL tunnel

As the grandeur of Sutong GIL tunnel project, to guarantee the security of the GIL transportation vehicle is one of the challenges. Therein, the safety characteristics of the batteries used in the GIL transportation vehicle is especially important due to the heaviness of the GIL equipment and the complex environment in the Sutong GIL tunnel.

In addition, due to the constrained space in the GIL tunnel for transportation, the transportation vehicle should be compact, and to extend the battery life, the energy density of the power battery should be high. On the other hand, due to the tight schedule for the Sutong GIL tunnel project, it puts forward high requirements for the reliability of the power batteries. In detailed, the power batteries should have been well industrialized, wide applied, and have mature manufacturing technologies.

Besides that, the Sutong GIL tunnel has the features of large slope and multi-variable diameter, while the GIL transportation vehicle moves in a fixed route. Therein the power consumption can be calculated during the construction. Then it is possible to compute the required battery capacity for the GIL transportation vehicle.

The detailed structure of Sutong GIL tunnel consists of several slopes. According to the construction procedure, the GIL project should start from the middle to both ends. Herein he GIL units will be transported and positioned from the north and south banks to the middle via the GIL special transportation vehicle. Then the project could be divided into two parts: south project and north project. Each project consists of different slopes as in Table 1. Here the south project consists of slopes S1~ S6, while the north project consists of slopes S6~ S8.

| Routes        | Slope segment | Slope length (km) | slope   |
|---------------|---------------|-------------------|---------|
| South Project |               |                   |         |
| S1            | 0.42          | 0.05              |         |
| S2            | 0.853         | 0.023457          |         |
| S3            | 0.36          | 0.05              |         |
| S4            | 0.3           | 0.005             |         |
| S5            | 0.3           | 0.005             |         |
| S6            | 0.502         | 0.031             |         |
| North Project |               |                   |         |
| S6            | 0.078         | 0.031             |         |
| S7            | 2.216         | 0.005             |         |
| S8            | 0.441         | 0.05              |         |
3.2. Battery for Sutong GIL special vehicle

Combined with the weight of Sutong GIL equipments and the chosen motor, it is possible to compute the charging and discharging power curves of the power batteries for the two routes of power, as shown in Fig.3 and (right)Fig.4.

![Power battery output power curve of the South Coast route](image1)

**Fig. 3. Output Power Curve of the Power Battery for the South Project**

![Power battery output power curve of the North Shore route](image2)

**Fig. 4. Output Power Curve of the Power Battery for the North Project**

At present, the most industrialized lithium-ion power batteries in China are lithium iron phosphate power batteries and ternary polymer power batteries. The difference between them is listed in Table 2. From it we find that ternary lithium batteries have the advantages in terms of capacity, power, and high rate charging, low-temperature performance. But in term of cyclic performance, the lithium iron phosphate batteries are better. Compared with ternary lithium batteries, lithium iron phosphate batteries are larger, heavier, and more expensive.

| Type                          | Lithium iron phosphate battery | Ternary lithium battery |
|-------------------------------|--------------------------------|-------------------------|
| gram specific capacity (mA·h/g) | 165                            | 160~185                 |
| working voltage (V)          | 3.4                            | 3.6~3.7                 |
| Rate capability              | WORSE                          | GOOD                    |
| cycles (times)               | 2000                           | 800                     |
| Low temperature performance  | WORSE                          | GOOD                    |
| High temperature performance | BEST                           | BETTER                  |
| Safety                        | BEST                           | BETTER                  |

From the perspective of safety, the ternary material has poor thermal stability under the same manufacturing environments. It will decompose, and release oxygen at the temperature of 200°C or so. Once catching fire, it will deflagrate in a short time. However, lithium iron phosphate has good thermal stability, and it will decompose at the temperature of 800°C or so. Even if it decomposes, it does not release oxygen. Therefore, extra oxygen is required for burning of the lithium iron phosphate battery. Once the oxygen source is cut off, the fire can be extinguished. Additionally, even the lithium iron phosphate catches fire, it does not burn vigorously. The fire spreads slowly, and it is easy to be extinguished.
For Sutong GIL special transportation vehicle, two types of lithium-ion power batteries satisfy the requirements of weight and size. But from the perspective of safety, lithium iron phosphate power batteries should be selected first.

4. Conclusion
This paper discussed the choice of power batteries for the Sutong GIL special transportation vehicle. The characteristics of various power batteries have been introduced and analyzed. Considering the slopes of the Sutong GIL tunnel, constrained space for the GIL special transportation vehicle, the weight of the GIL equipment, safety, etc. the lithium iron phosphate power batteries are chosen for the GIL special transportation vehicle. It satisfies the requirements of Sutong GIL tunnel project, and helps to successfully complete the project within the tight schedule.

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