Application Prospect of High Strength Aluminum Alloy in Transmission Tower

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Abstract. Transmission Towers are usually made of steel and protected from corrosion by hot dip galvanizing. This paper explores the application of high strength aluminum alloy to solve the problems of atmospheric corrosion of transmission tower in coastal area and heavy industry pollution area, sand erosion of zinc coating of transmission tower in strong wind sand area, and transportation difficulty in rugged mountain area. Compared with the traditional steel tower, the design and development of high-strength Aluminum Alloy transmission tower has remarkable characteristics. First, the high-strength Aluminum Alloy transmission tower does not need the traditional hot-dip galvanizing process of steel, which can reduce the pollution to the atmosphere and soil environment; Second, the density of Aluminum Alloy material is 1/3 of that of steel, which can reduce the difficulty of construction and reduce transport costs; third, high-strength Aluminum Alloy has good corrosion resistance, and there is no need for routine antiseptic maintenance as steel tower. The application of high strength aluminum alloy transmission tower in area with severe atmospheric corrosion, strong wind sand and mountainous area has high engineering application value.

Keywords: High Strength Aluminum Alloy, Transmission Tower, Hot-dip Galvanizing, Corrosion Resistance

1. Introduction
With the rapid development of China Power Grid, State Grid Co. Ltd. has built a huge and complex power grid with UHV transmission lines as the backbone. Transmission line path is long; covering a wide area, local corridor section line is dense, transmission line between or with high-speed railway line cross-over. The areas along the overhead line are mostly plateau and mountain area, heavy ice area and strong wind area, the natural environment is bad, the geological topography is complex, the climate is changeable. During the construction of transmission lines in rugged mountainous areas, part of the work still needs human and animal power to complete, which is difficult and costly[1], as shown in Fig.1.
Fig 1. Difficulties in transport of tower materials

Because of long-term exposure to the atmosphere, the tower material of transmission line may be corroded under the combined effect of Wind, rain, Snow and frost. Hot-dip galvanizing is often used in transmission towers to prevent corrosion, which requires special procedures such as rust removal, pickling and galvanizing. The investment is huge, and the process is highly polluting.

Usually, the zinc solution needs to be heated to about 450°C, which will release harmful gas and endanger people's health; especially the CR6+ in the passivation solution of zinc plating has great harm to human body and environment. Zinc plating, increased the manufacturing cost of Iron Towers, and in the sea, acid rain and industrial atmosphere and other serious corrosion environment, the life of zinc coating is generally about 10 years, lower than the line service life, in the course of line operation, anticorrosive maintenance still needs to be carried out by means of painting anticorrosive paint [2], as shown in Fig.2.

Fig 2. Tower corrosion

In the transmission line structure, the aluminum alloy material takes the stressed structure, mainly applies in the hold pole and the rapid repair tower [3]. Lindsey Company in the United States, SBB Company and Tower solutions Company in Canada has a huge market share of rapid repair tower. The repair towers are made of 6061-T6 aluminum alloy with good weldability, and the yield strength is 240MPA. Many kinds of structures of emergency repair tower have been developed, and a mature series of emergency repair system has been formed. It has the following characteristics: modularization, universality, lightweight, serialization and intelligence. Because of these characteristics, it can be used according to the actual conditions of the accident line, as shown in Fig.3.
In addition to 6061-T6 aluminum alloy, 2A12-T4 high strength aluminum alloy is used in China Rush Repair Tower [4]. The yield strength reaches 295MPA and bolt or rivet connection is adopted. The existing aluminum alloy transmission line structures are all used in the cable-stayed tower structure, and the members are mostly controlled by the integral stability of the tower. The transmission steel tower has the problems of transportation difficulty and corrosion. The application of high strength aluminum alloy in the self-standing Transmission Tower can reduce the weight of the tower and avoid galvanizing by its light weight, high strength and corrosion resistance. It solves the problems of difficulty and high cost of Tower Material Transportation and tower erection in rugged mountain area, the problems of environmental pollution caused by traditional hot-dip galvanizing of iron tower, and the problems of regular anticorrosion and maintenance of transmission tower during operation.

2. Analysis of Dynamic Characteristics of Aluminum Alloy Tower
Taking China 2E15 double circuits’ transmission tower as an example, the dynamic characteristics of the tower and the Aluminum Alloy Tower are compared. The tower structure is shown in fig.4.
Fig 4. 2E15 transmission tower

2.1. Vibration Frequency Analysis
The vibration frequency of the suspended tower 2E15-SZC1 is shown in Table 1, and that of the Tension Tower 2E15-SJC1 is shown in Table 2.

| Table 1. Vibration frequency of Suspended tower 2E15-SZC1 |
|----------------------------------------------------------|
| Height of cross arm | Aluminum Tower | Steel tower |
|                   | 1st order | 2nd order | 3rd order | 1st order | 2nd order | 3rd order |
| 18                | 1.83     | 1.86      | 4.54      | 2.38      | 2.42      | 4.97      |
| 21                | 1.73     | 1.75      | 4.40      | 2.25      | 2.28      | 4.82      |
| 24                | 1.69     | 1.71      | 4.38      | 2.13      | 2.16      | 4.88      |
| 27                | 1.65     | 1.66      | 4.30      | 2.05      | 2.07      | 4.79      |
| 30                | 1.58     | 1.59      | 4.28      | 2.00      | 2.02      | 4.74      |
| 33                | 1.52     | 1.53      | 4.32      | 1.92      | 1.93      | 4.59      |

| Table 2. Vibration frequency of Tension Tower 2E15-SJC1 |
|--------------------------------------------------------|
| Height of cross arm | Aluminum Tower | Steel tower |
|                   | 1st order | 2nd order | 3rd order | 1st order | 2nd order | 3rd order |
| 18                | 2.75     | 2.78      | 5.50      | 3.00      | 3.06      | 5.24      |
| 21                | 2.58     | 2.60      | 5.28      | 2.85      | 2.90      | 5.10      |
| 24                | 2.53     | 2.56      | 5.31      | 2.72      | 2.76      | 5.17      |
| 27                | 2.40     | 2.42      | 5.07      | 2.61      | 2.64      | 5.03      |
| 30                | 2.29     | 2.31      | 5.04      | 2.51      | 2.54      | 5.03      |

As a new type of material, the dynamic characteristics of Aluminum Alloy Tower are similar to that of iron tower. The design method is similar.

3. Wind-induced Vibration Analysis of Aluminum Alloy Tower
Wind-induced Vibration Coefficient is an important factor of wind-induced response of structures, and it is also an important parameter affecting the design of structures [5-8].

According to the calculation method of wind vibration Coefficient in DL/T551-2018(Chinese Load code for the design of overhead transmission line), the wind vibration coefficient of suspended tower and Tension Tower with steel and high strength aluminum alloy are analyzed and calculated [9-10].
Wind-induced Vibration Coefficient of the suspended tower 2E15-SZC1 is shown in Table 3, and that of the Tension Tower 2E15-SJC1 is shown in Table 4.

**Table 3. Wind-induced Vibration Coefficient of the suspended tower 2E15-SZC1**

| position          | Aluminum Tower | Iron tower | Ratio (AL/Ir) |
|-------------------|----------------|------------|---------------|
| Ground Wire support 1 | 4.10           | 3.92       | 1.05          |
| Ground Wire support 2 | 2.82           | 2.68       | 1.05          |
| Cross arm 1       | 3.03           | 3.06       | 0.99          |
| Cross arm 2       | 2.51           | 2.48       | 1.01          |
| Cross arm 3       | 1.92           | 1.83       | 1.05          |
| Tower body        |                |            |               |
| Ground Wire support |               |            |               |
| Ground Wire support |               |            |               |
| Cross arm 1       | 1.65           | 1.58       | 1.04          |
| Cross arm 2       | 1.82           | 1.68       | 1.08          |
| Cross arm 3       | 1.33           | 1.25       | 1.06          |
| Tower body        | 1.56           | 1.50       | 1.04          |
| Tower body        | 1.18           | 1.14       | 1.03          |
| Tower body        | 1.52           | 1.32       | 1.15          |
| Tower body        | 1.29           | 1.17       | 1.10          |
| Tower body        | 1.15           | 1.11       | 1.03          |
| Tower body        | 1.10           | 1.07       | 1.03          |
| Tower body        | 1.06           | 1.04       | 1.02          |
| Tower body        | 1.00           | 1.00       | 1.00          |

**Table 4. Wind-induced Vibration Coefficient of the Tension Tower 2E15-SJC1**

| position          | Aluminum Tower | Iron tower | Ratio (AL/Ir) |
|-------------------|----------------|------------|---------------|
| Ground Wire support | 2.82           | 2.73       | 1.03          |
| Cross arm 1       | 3.00           | 3.02       | 0.99          |
| Cross arm 2       | 2.41           | 2.26       | 1.07          |
| Cross arm 3       | 2.08           | 1.87       | 1.11          |
| Tower body        |                |            |               |
| Ground Wire support |               |            |               |
| Ground Wire support |               |            |               |
| Cross arm 1       | 1.67           | 1.51       | 1.11          |
| Cross arm 2       | 1.93           | 1.93       | 1.00          |
| Cross arm 3       | 1.61           | 1.45       | 1.11          |
| Tower body        | 1.87           | 1.66       | 1.13          |
| Tower body        | 1.87           | 1.71       | 1.09          |
| Tower body        | 1.33           | 1.24       | 1.07          |
| Tower body        | 1.67           | 1.47       | 1.14          |
| Tower body        | 1.67           | 1.54       | 1.09          |
| Tower body        | 1.21           | 1.15       | 1.05          |
| Tower body        | 1.67           | 1.43       | 1.17          |
| Tower body        | 1.38           | 1.28       | 1.08          |
| Tower body        | 1.27           | 1.22       | 1.04          |
| Tower body        | 1.19           | 1.15       | 1.03          |
| Tower body        | 1.09           | 1.09       | 1.01          |
| Tower body        | 1.04           | 1.04       | 1.00          |
As a new material, the distribution of wind-induced Vibration Coefficient of Aluminum Alloy Tower is similar to that of iron tower, and its value is 1% ~ 17% larger than that of iron tower [11].

4. Weight Comparison between Aluminum Alloy Tower and Iron Tower
The strength design values of high strength aluminum alloys are shown in table 5.

| Materials          | brand | Heat treatment condition | strength of Tension, compression and bend ,f(N/mm²) | Shear Strength, fv (N/mm²) |
|--------------------|-------|--------------------------|-----------------------------------------------------|-----------------------------|
| Aluminum Alloy     | X703  | T6                       | 360                                                 | 210                         |

The Aluminum Alloy Tower is designed according to GB50429 (in chinese, Code for aluminium structures), and Iron tower designed according to DL/T 5154 (in chinese, Technical code for the design of tower and pole structures of overhead transmission line). Weight of each tower is shown in table 6.

| Tower type          | Weight | Ratio (AL/Ir) |
|---------------------|--------|---------------|
|                     | Aluminum Tower | Iron tower |     |
| 2E15-SZC1-33        | 10.29   | 15.18         | 0.68 |
| 2E15-SZC2-36        | 12.47   | 18.33         | 0.68 |
| 2E15-SZC3-42        | 16.50   | 23.86         | 0.69 |
| 2E15-SZC4-45        | 19.75   | 28.15         | 0.70 |
| 2E15-SZCK-54        | 21.01   | 30.13         | 0.70 |
| 2E15-SJC1-30        | 16.92   | 26.12         | 0.65 |
| 2E15-SJC2-30        | 18.72   | 28.16         | 0.65 |
| 2E15-SJC3-30        | 21.32   | 32.52         | 0.66 |
| 2E15-SJC4-30        | 22.70   | 35.75         | 0.63 |
| 2E15-SDJC-30        | 23.43   | 36.16         | 0.65 |

According to the calculation and analysis of a series of towers, the weight of high-strength Aluminum Alloy Towers is about 63% ~ 70% of the weight of iron towers.

5. Conclusion
(1) High-strength Aluminum Alloy Tower has good corrosion resistance, can avoid galvanizing pollution routine anti-corrosion maintenance;
(2) The density of high strength material is 1/3 of Steel, which reduces the construction difficulty and construction cost
(3) Under the same design conditions, the weight of high strength aluminum alloy tower is 10% lower than that of iron tower.
(4) High-strength aluminum alloy towers are suitable for transmission lines in coastal areas, industrial pollution areas and rugged mountainous areas.

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