# Calculation and analysis of drainage board temperature for tension clamp

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**Abstract.** Tension clamp, as an important fitting on transmission line, plays a key role in connecting conductor and transmitting mechanical load. Since the power grid is in operation, the overheating phenomenon of tension clamp drainage board caused by poor connection quality of contact fittings has become increasingly prominent, and has become a serious accident threatening normal operation of transmission lines. In this paper temperature calculation model of drainage board was established, and the temperature was calculated, and influence of wind speed, ambient temperature, current and type on drainage board temperature was studied. The results show that drainage board temperature decreases as wind speed raises, and drainage board temperature increases as ambient temperature and current increase. Drainage board temperature of different types of tension clamp is different. The drainage board with larger size usually has lower temperature.

**Key words:** tension clamp, drainage board, heat transfer, ambient temperature, wind speed, current

## 1. Introduction

Along with rapid economic development, power demand continues to rise gradually and the construction scale of transmission project expands rapidly. With the construction and operation of UHV project, China's power grid has become the AC/DC hybrid grid with the most complex structure and the largest scale in the world [1, 2]. Up to 2019, the length of AC transmission lines for the voltage of 500kV and above is 228000 km, and the length of DC transmission lines for the voltage of ±400kV and above is 42000 km, which leads to the application of clean energy and improvement of environment and security level [3].

Electrical connection is one of the most important components of power transmission and transformation project [4]. It is an essential and abundant link in power electronic equipment and power grid system. Many industrial electrical appliances cannot get rid of the huge and bulky electrical contacts. Tension clamp, as an important fitting on transmission line, plays a key role in connecting conductor and transmitting mechanical load. Tension clamp drainage board is generally connected by lapping with bolts, and the connection quality is an important factor affecting the system safety factor and mean time between failures, which directly influences the safe and stable operation of power transmission projects [5]. Since the power grid is in operation, the overheating phenomenon of tension clamp drainage board caused by poor connection quality of contact fittings has become increasingly prominent [6]. Especially in summer, under the conditions of large power load and high temperature environment, the overheating fault of drainage plate is more likely to occur, which has a serious impact on the reliability of transmission. Investigations show that the overheating of tension clamp drainage board has shown a trend of frequent occurrence, and has become a serious accident threatening safe operation of transmission lines.

Therefore, heat transfer process of the tension clamp drainage board was studied. The heat transfer calculation model was established, and the temperature calculation of the drainage board under different boundary conditions was carried out, and the influencing factors were analyzed.

## 2. Drainage board of tension clamp

Tension clamps are used to fix the conductors on the tension insulator string for anchoring, and also used to fix the stay wire [7]. According to the structure, tension clamp can be divided into bolt clamp, wedge clamp and compression clamp. At present, compression type tension clamps are commonly used in transmission lines, especially for UHV transmission lines [8].

The compression type tension clamp consists of aluminum tube and steel anchor. Steel anchor is applied to combine steel wires and then put into the aluminum tube. By compression, the plastic deformation of the metal occurs, which leads to the combination of the clamp and the conductor. The structural form is shown in Fig. 1. In general, the steel anchor of the tension clamp carry nearly all the load of the conductor, so the mechanical strength is matched with the rated tensile strength of the conductor.

Compression type tension clamp can be installed through hydraulic pressure or explosive pressure. When hydraulic pressure is used, a certain specification of steel mold needs to be compressed. The shapes of steel pipe and aluminum pipe should be circular. After compression, they will become regular hexagon. The opposite side size of the hexagon should be 0.866 times of the outer diameter of the pipe. When explosion pressure is used, primary explosion pressure or secondary explosion pressure could be used. Before explosion pressure, keeping 10 mm length of inner layer the aluminum wire into the anti-burning hole of the steel anchor, which will protect the steel core from burning.

In this paper, three types of tension clamp drainage board are selected, as shown in Fig. 2, which are NY-1250/100A, NY-1000/80A, NY-500/65A respectively. The drainage boards are double board overlapping single board.

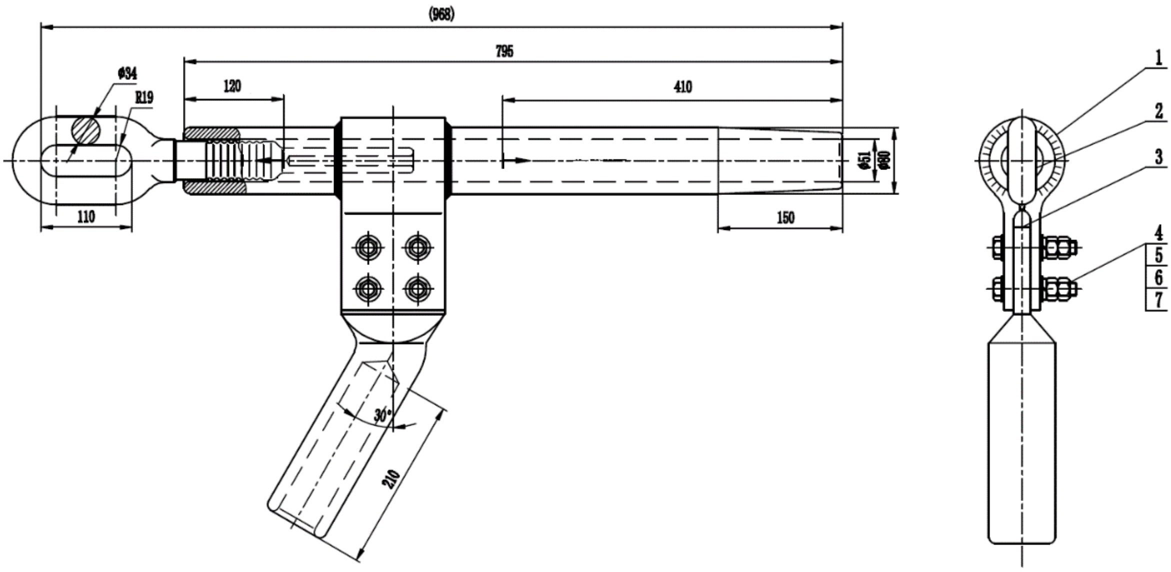
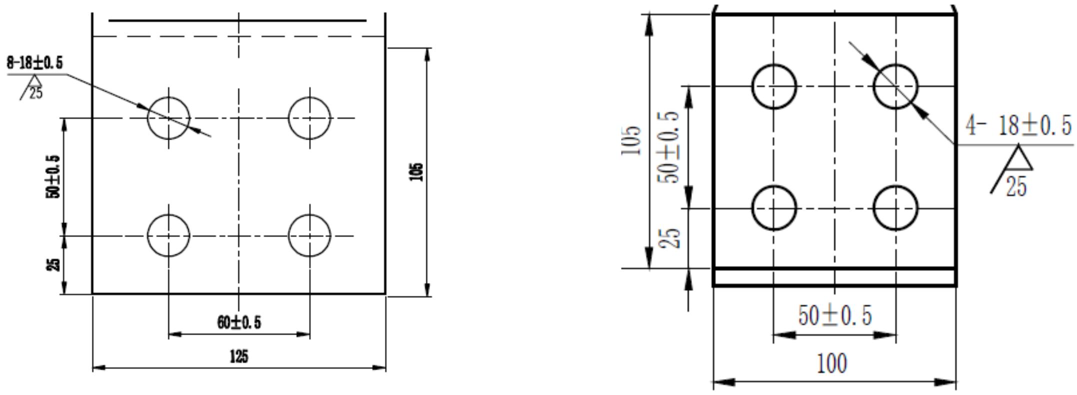
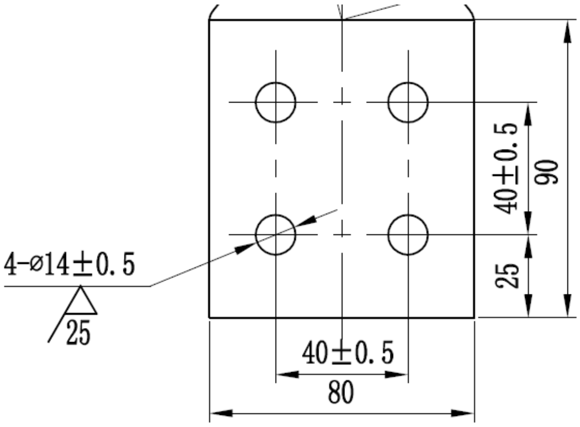



**Fig. 1** Tension clamp NY-1250/100A




(a) NY-1250/100A (thickness 20mm) (b) NY-1000/80A (thickness 20mm)




(c) NY-500/65A (thickness 16mm)

**Fig. 2** Structure of drainage board

## 3. Temperature calculation model

When the drainage board is in operation, the Joule heat generated by current will lead to the increase of the drainage board temperature. The temperature will increase to a certain value until absorbed heat is the same as the dissipated heat. Then the equation for temperature calculation can be set up [9, 10].

$$q_j = q_c + q_r \tag{1}$$

$$\begin{cases} q_j = I^2 R \\ q_c = hA\left(T_f - T_e\right) \\ q_r = \varepsilon\sigma A\left(T_f^{\,4} - T_e^{\,4}\right) \end{cases} \tag{2}$$

where,

$I$-current, A;

$R$-drainage board resistance, Ω;

$h$-convective heat transfer coefficient, W/(m$^2$ K);

$A$-drainage board surface area, m$^2$;

$T_c$-drainage board temperature, K;

$T_e$-ambient temperature, K

Based on equations (1) and (2), the drainage board temperature could be calculated. The convective heat transfer coefficient can be calculated as follows.

Convective heat transfer is caused by the relative movement between various parts because of the mixing of cold and hot fluids, which includes natural and forced convective heat transfer. Natural convective heat transfer is caused by the difference of cold fluids density and hot fluids density, while forced convective heat transfer is caused by the action of water pump, fan or other pressure difference. When calculating the convection heat coefficient, it is usually necessary to calculate the Nusselt number firstly, and then calculate the convection heat coefficient according to the following equation.

$$h = \frac{Nu \cdot \lambda}{l} \tag{3}$$

where,

$\lambda$-thermal conductivity, W/(m K);

$L$-characteristic length, m.

For natural convective heat transfer, *Nu* can be calculated according to the correlation of large space natural convection experiment, and the equation is as follows:

$$Nu = C\left(Gr \cdot Pr\right)^n \tag{4}$$

$$\begin{cases} Gr = \dfrac{gl^3\alpha_v(T_f - T_e)}{\nu^2} \\ Pr = \dfrac{\mu c_p}{\lambda} \end{cases} \tag{5}$$

Where,
*G*-the gravity acceleration, m/s$^2$;
$\alpha_v$-volume expansion coefficient, 1/K;
$\nu$-kinematic viscosity, m$^2$/s;
$\mu$-dynamic viscosity, N s/m$^2$;
$c_p$-specific heat capacity, J/(kg K).
The value of *C* and *n* can be determined based on the following table.

**Table 1.** Value of C and n

| Gr | C | N |
|---|---|---|
| 1.43×104<Gr≤3×109 | 0.59 | 1/4 |
| 3×109<Gr≤2×1010 | 0.0292 | 0.39 |
| Gr>2 ×1010 | 0.11 | 1/3 |

For forced convective heat transfer, Nu can be calculated according to the experimental correlation of gas across a cylinder, and the equation is as follows,

$$Nu = CRe^n Pr^{1/3} \tag{6}$$

$$Re = \frac{ul}{\nu} \tag{7}$$

Where,
*C*-0.228;
*N*-0.731;
*u*-speed, m/s.
According to the above analysis, *Nu* of natural and forced convective heat transfer could be obtained, and then the heat transfer coefficients can be obtained, and the corresponding convective heat transfer can be studied.

## 4. Analysis of drainage board temperature

According to temperature calculation model, the drainage board temperature was calculated, and influence of wind speed, ambient temperature, current and type on drainage board temperature was studied.

### 4.1. Wind speed

The drainage board temperature under different calculation conditions shown in Table 2 was calculated, as shown in Fig. 3

**Table 2.** Calculation conditions

| Type | NY-1250/100A |
|---|---|
| Ambient temperature (°C) | 20 |
| Wind speed (m/s) | 0~10 |
| Current (A) | 5000 |

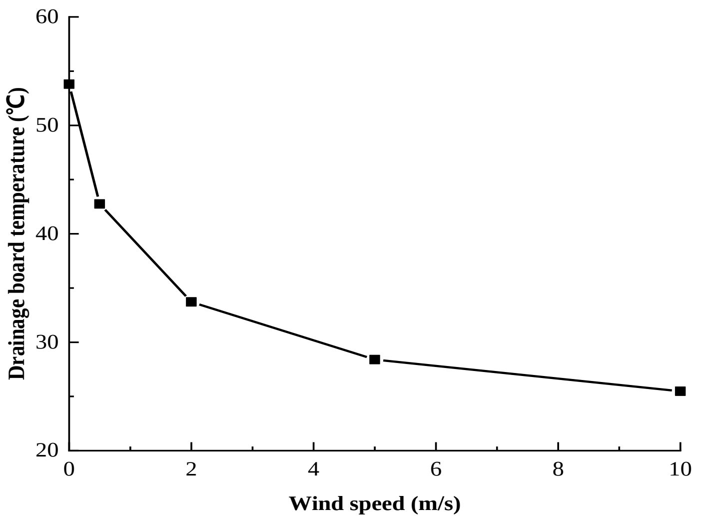



**Fig. 3** Influence of wind speed on drainage board temperature

According to Fig. 3, it's obvious that the drainage board temperature decreases as the wind velocity increases. At a low speed, the temperature decreases rapidly, and then the temperature decreases slowly when wind speed is large. Wind speed influences the drainage board temperature through convective heat. When wind speed increases, convective heat will increase, leading to the decrease of drainage board temperature. Besides, with the increase of wind speed, it has less influence on drainage board temperature

## 4.2. Ambient temperature

The drainage board temperature under different calculation conditions shown in Table 3 was calculated, as shown in Fig. 4.

According to Fig. 4, it's obvious that the drainage board temperature increases gradually as the ambient temperature increases, and the change is basically linear. Ambient temperature influences the drainage board temperature through dissipated heat, include convective heat and radiant heat. When other calculation conditions keep the same, the difference between drainage board temperature and ambient temperature will show a linear change as the ambient temperature changes, which leads to a linear relationship between drainage board temperature and ambient temperature.

**Table 3.** Calculation conditions

| Type | NY-1250/100A |
|---|---|
| Ambious temperature (°C) | -10~30 |
| Wind speed (m/s) | 0.5 |
| Current (A) | 5000 |

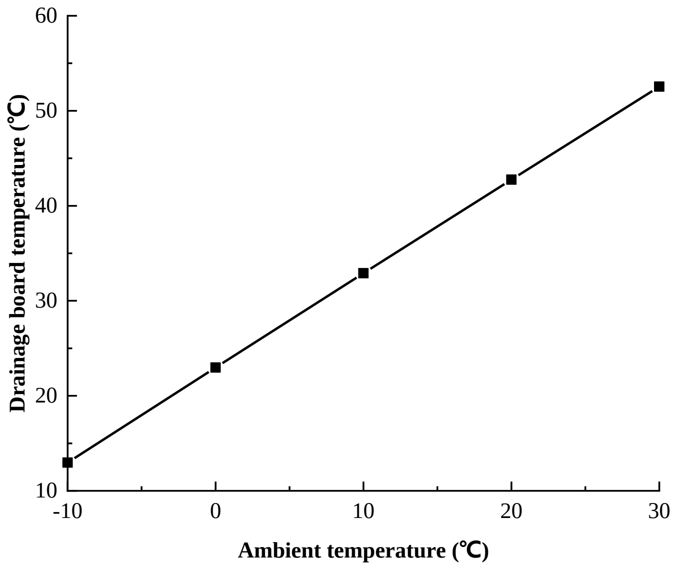



**Fig. 4** Influence of ambient temperature on drainage board temperature

### 4.3. Current

The drainage board temperature under different calculation conditions shown in Table 4 was calculated, as shown in Fig. 5.

**Table 4.** Calculation conditions

| Type | NY-1250/100A |
|---|---|
| Ambient temperature (°C) | 20 |
| Wind speed (m/s) | 0.5 |
| Current (A) | 0~5000 |

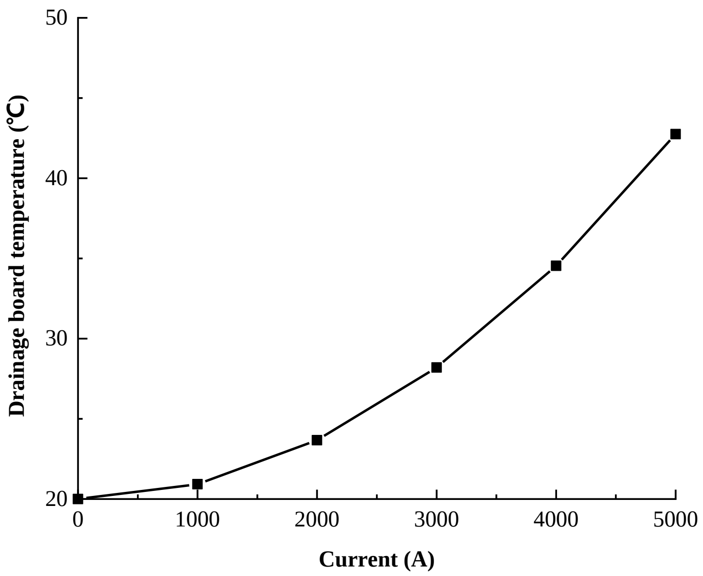



**Fig. 5** Influence of current carrying capacity on drainage board temperature

According to Fig. 5, it’s obvious that drainage board temperature increases as current carrying capacity increases, and the relationship of drainage board temperature and the square of current carrying capacity is approximately linear. Current carrying capacity influences drainage board temperature through the generated Joule heat. Because the Joule heat is linear with the square of the current, the temperature of the drainage board is also approximately linear with the square of the current.

### 4.4. Type

The drainage board temperature under different calculation conditions shown in Table 5 was calculated, as shown in Fig. 6.

According to Fig. 6, it's obvious that under the same calculation conditions, the drainage board temperature of three types of tension clamp is different. The drainage board temperature of tension clamp NY-1250/100A is the lowest, while NY-500/65A is the highest. The sizes and resistances of the drainage board are different. NY-1250/100A has the largest size and the smallest resistance, which means least Joule heat and largest heat transfer area, resulting in better heat dissipation between drainage board and environment, leading to the lowest temperature.

**Table 5.** Calculation conditions

| | |
|---|---|
| Type | NY-1250/100A<br>NY-1000/80A<br>NY-500/65A |
| Ambient temperature (°C) | 20 |
| Wind speed (m/s) | 0.5 |
| Current (A) | 5000 |

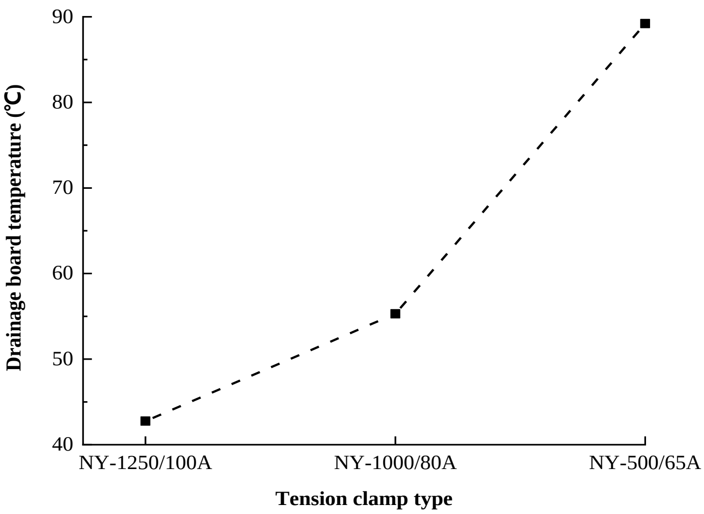



**Fig. 6** Influence of tension clamp type on drainage board temperature

## 5. Conclusion

Temperature calculation model of drainage board was set up, and drainage board temperature under different conditions was calculated. Based on calculation results, influence of wind speed, ambient temperature, current and type on drainage board temperature was studied.

(1) Temperature calculation model of drainage board was set up, and drainage board temperature under different calculation conditions was calculated.

(2) When wind speed increases, drainage board temperature decreases.

(3) When ambient temperature increases, drainage board temperature increases, and the increase is nearly linear.

(4) When current increases, drainage board temperature increases, and the relationship of drainage board temperature and the square of the current is approximately linear.

(5) Under the same environment conditions, the drainage board temperature of different types of tension clamp is different. The drainage board with larger size usually has lower temperature.

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## References

[1] Zhou X, Yi J, Song R, et al. An overview of power transmission systems in China[J]. Energy, 2010, 35(11): 4302-4312.

[2] Wang Y, Zhou M, Zhang F, et al. Chinese grid investment based on transmission and distribution tariff policy: An optimal coordination between capacity and demand[J]. Energy, 2021, 219(21): 119589.

[3] Huang D, Ruan J. Recent Developments of UHV DC Transmission Research in China[J]. Clinical Science, 2008: 535-540.

[4] Chen W H, Cheng Y D, Li P Z, et al. The mathematical model of the reliability of aerospace electric connector[J]. Chinese Journal of Aeronautics, 1997, 6(1): 93-95

[5] Sung I H, Kim J W, Noh H J, et al. Effect of displacement and humidity on contact resistance of copper electrical contacts[J]. Tribology International, 2016, 95(1): 256-261.

[6] Sun X B, Wang H W, Wang F. Reliability assessment for a certain type of electrical conductor based on accelerated degradation data[J]. Journal of Naval Aeronautical and Astronautical University, 2014, 7(5): 67-71.

[7] Lalonde S, Guibault R, Langlois S. Numerical analysis of ACSR conductor-clamp systems undergoing wind-induced cyclic loads[J]. IEEE Transactions on Power Delivery, 2017: 1518-1526.

[8] Ye Z, Pang K, Y Du, et al. Simulation Analysis of the Tensile Mechanical Properties of a Hydraulic Strain Clamp-Conductor System[J]. Advances in Materials Science and Engineering, 2020(41): 1-19.

[9] Mikhail V M, Sergey D. Numerical modelling of contact heat transfer problem with work hardened rough surfaces[J]. International Journal of Heat and Mass Transfer, 2015, 90(1): 72-80.

[10] Morgan V T. The current distribution, resistance and internal inductance of linear power system conductors-a review of explicit equations[J]. IEEE Trans. Power Delivery, 2013, 28: 1252-1262.