Research on the Selection of Helicopter Patrol Equipment for Overhead Transmission Line at High Altitude

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Abstract. The requirement for models and airborne equipment of helicopter patrol that operate on overhead transmission lines in high altitude areas is quite different from the equipment used in ordinary area. Especially in Yunnan with its complex terrain, the selection of helicopter patrol equipment is particularly crucial considering large difference in relative altitude. Based on the characteristics of Yunnan Power Grid, this paper focuses on the selection of models and airborne equipment of helicopter patrol used in the overhead transmission line operating at altitudes of 2500 meters and above. The suitable equipment for overhead line patrol at high altitude is determined to ensure the safety and quality of operations.

Introduction

Helicopter patrols have continued to increase in size since the successful piloting on overhead transmission lines in Yunnan in 2006. Practice has shown that helicopter patrols have reduced the labor intensity of patrolling personnel, compensated for the defects in ground patrol methods, and greatly improved the quality and efficiency of overhead line inspections, and that they play an important role in ensuring the safe and stable operation of power grid[1-3]. With the increasing scale of Yunnan power grid equipment, the high altitude transmission lines of 220kV and above are growing more and more in Zhao-tong, Chu-xiong, Nu-jiang, Da-li, Li-jiang, Di-qing and other areas inside Yunnan. Therefore, there is an urgent need to use helicopter advantages to make up for the lack of manual inspections, especially during the annual snowfall season, when human cannot carry out inspection operations. However, at present, the Bell 206L helicopter used in Yunnan Power Grid conducts line inspection work mainly at altitudes below 2500 meters. It is limited by the aircraft type and the technical performance of airborne equipment and cannot meet the needs of work. Therefore, it is necessary to consider the characteristics of Yunnan in the research on helicopter type and onboard equipment selection, to meet the inspection requirements of transmission line at high altitude areas, and the research results should be verified in practice to solve the technology bottleneck of helicopter inspection in high altitude transmission lines, and to continuously improve the application ability of helicopter inspections in Yunnan Power Grid, to provide technical support for power grid companies to grasp the health status of power equipment more comprehensively, more timely accurately[4-9].

Selection of Helicopter Models

Factors Affecting Helicopter Performance at High Altitude

(1) Air density. The engine power decreases as the altitude increases. The increase in the pull force coefficient of helicopter rotor wing is also less than that in the low altitude environment, and the loss of helicopter rotor power is about 1/3 of those at lower altitudes.

(2) Temperature. The temperature drop reduces the maximum torque of the engine, especially in the helicopter icing state, when the maximum torque drop has a significant effect (the effect curve is...
shown in Fig. 1. In addition, the low temperature environment will reduce the reliability of helicopter electronic equipment and lower the battery energy storage performance.

(3) Mechanical performance. In high altitude regions, most helicopter engines are running in high-power state, and their long-time use increases the load of the corresponding helicopters. Long-term operation in overload state increases the probability of damage to components.

(4) Airflow changes. In high altitude mountainous regions, the air flow changes rapidly and the turbulence conditions are prominent. To overcome the effects of abrupt changes in air flow, helicopters need to have greater power reserves.

(5) Influence of topography and landforms. The terrain and geomorphology in high altitude areas are complex, making wireless communication difficult. The quality of navigation signals is low, and problems such as the indication error of the radio compass are prominent. Automatic control capability of the helicopter is restricted, and the pilot’s technical level is more tested.

**Main Performance Requirements of the Patrol Helicopter at High Altitude**

Under the analysis of the factors of high altitudes on helicopter performance, combined with the patrol operations of overhead transmission lines, the performance requirements of helicopters focused on patrolling operations at high altitude lines are proposed as follows.

**Hover Performance.** Hovering can be divided into two categories: hovering with ground effect and hovering without ground effect. The ground effect means the rotor wash-down airflow will be affected by the ground when the helicopter is close to it. Changes in the flow field caused by obstacles on the ground reduce the induced power of the rotor consumption (for accelerating the air flow through the rotor), which means the required power to keep hovering of helicopter is less than that without ground effect. Helicopters can hover at higher altitudes with ground effect. In the process of patrolling, at the speed from 15 to 20km/h, the helicopters need to hover when it encounters vulnerable areas, observation areas. And the average altitude of lines in high altitude areas is 3000 meter in Yunnan, with 220kV Fulan Line reaching 4300 meters. For that, and the height of the high altitude line and helicopters should leave a certain degree of space, so we suggest the hover height of selected helicopter should reach 4500 meters.

**Ceiling.** The ceiling is the “extreme height that an aircraft can achieve on its own capabilities”, generally refers to the practical ceiling. The practical ceiling is the maximum flying height at which a helicopter can maintain its level of flight in a vertical plane with a given weight and engine operating conditions. The altitude of some areas in Yunnan is generally higher, so the helicopter’s ceiling is required. It should not be less than 5000m for the actual altitude.

**Load Performance.** High-altitude helicopters are generally required to carry 4 crew members, including one captain, one assistant driver, and two airline crews. In addition, one device of patrol line is needed. According to the configuration of a four-person helicopter, the requirements for helicopter lifting should be at least 500kg. Therefore, the selection criteria of high-altitude helicopter inspection model, used to measure the helicopter's load performance, does not require as much cabin space or load capacity as the transport plane. The key is to look into the performance of each model under the inspection load conditions.

**Reliability Analysis of other Equipment.** It is mainly required that all types of airworthy
on-board instruments, equipment, and batteries, etc., are highly reliable in high-altitude and harsh environments.

**Comparison of Major Helicopter Models**

According to the performance requirements of the helicopter flight in the highland area, there are four types of aircraft that are commonly used at home and abroad to meet the patrol operation needs of overhead transmission lines above 3000 meters: AS350B3 (European Direct Small Squirrel), Bell 407GPX, T2e (EC135T2e), and Bell429.

**Comparison of Single-engine Helicopters.** It can be seen from Table 1 the highest cruising speed and plug-in capacity of 407GXP is slightly lower than that of AS350B3, and the procurement cost is slightly higher. But 407GXP has better plateau performance, more advanced avionics systems and better cockpit visibility.

| Model                | AS350B3 | Bell 407GXP |
|----------------------|---------|-------------|
| Maximum external cargo weight (kg) | 1400 | 1200 | Rotor diameter (m) | 10.69 | 10.66 |
| Payload (kg)         | 1013    | 1065 | Body length (m)   | 10.93 | 10.57 |
| Maximum cruise speed (km/h) | 265   | 246 | Landing gear width (m) | 2.28 | 2.64 |
| Expected maximum operating altitude (m) | 5000 | 5200 | Machine height (m) | 3.24 | 3.30 |
| Largest hover altitude (m) | 5420 | 5520 | Cabin size LxWxH (m³) | 3.0  | 3.0  |
| Maximum range (standard fuel tank) (km) | 657 | 675 | Empty weight (kg) | 1228 | 1191 |
| Life time (standard fuel tank) (h) | 4.3  | 4.2 | Maximum take-off weight (kg) | 2250 | 2722 |
| Purchase cost (ten thousand yuan) | 2200 | 2300 | Maximum number of seats | 6    | 7    |

**Comparison of Double-engine Helicopters.** By comparison in Table 2, Bell 429 is stronger than EC135T2e in terms of various performances such as highest cruising speed, cabin space, and payload.

| Model                | EC135T2e | Bell 429 |
|----------------------|----------|----------|
| Rotor diameter (m)   | 10.21    | 10.97    | Payload (kg) | 1255 | 1371 |
| Body length (m)      | 12.16    | 13.11    | Maximum cruise speed (km/h) | 252  | 278  |
| Landing gear width (m) | 2.79   | 2.67 | Expected maximum operating altitude (m) | 3000 | 3000 |
| Machine height (m)   | 3.51     | 4.04 | Largest hover altitude (m) | 3099 | 3438 |
| Cabin size LxWxH (m³) | 4.6    | 5.8  | Maximum range (standard fuel tank) (km) | 635  | 722  |
| Empty weight (kg)    | 1482     | 1925    | Life time (standard fuel tank) (h) | 3.5  | 3.8  |
| Maximum take-off weight (kg) | 2910 | 3402 | Maximum number of seats | 7    | 7    |
| Maximum external cargo weight (kg) | 600  | 1361 | Purchase cost (ten thousand yuan) | 4500 | 4800 |

**Comprehensive Comparison, Analysis and Selection.** For the main performance requirements and the comparison of mainstream model parameters, double-engine Bell 429 and EC135T2e have better wind resistance and safety performance than other brands of helicopter, but the estimated maximum altitude of their operations cannot meet the inspection conditions of high altitude mountainous regions in Yunnan, and the operation is more costly. The performance parameters of single-engine helicopters Bell 407GXP and AS350B3 are more suitable for the characteristics of high altitude helicopter inspection operations in Yunnan. Bell 407GXP has better technical parameters, but it is the latest model in 2015, with few domestic ownership and applications. The AS350B3 helicopter once successfully took off and landed on Everest (8848 meters) in May 2005, and its technology is relatively mature. So AS350B3 (small squirrel) is the preferred choice for flight verification.

**Selection of Onboard Pods**

**Selection Principles for Pods in High Altitude Helicopter Patrols**

As the main tool for helicopter patrols, onboard pods directly affect the quality and operating costs of operations. High-altitude helicopter patrol aircraft should be able to effectively cope with the
complex and harsh environmental conditions of high altitude. Its main technical performance requirements are analyzed as follows.

1. The effect of pressure. Due to the large pressure difference between the inside and outside of the equipment, the equipment sealing standard is required to be higher. The equipment is required to function at an altitude of at least 4500 meters and can withstand a pressure difference of no less than 1.5 times the standard atmospheric pressure.

2. The influence of ambient temperature. Due to the prone to extremely low temperature conditions at high altitudes, the equipment is required to have a relatively large adaptability to ambient temperature. Normal functional temperature should meet -20~55°C, and the temperature difference adaptability should meet 5°C/min change.

3. Performance to resistant wind and rain. The pods are required to have airworthiness certification. The exterior design should have good performance to resistant wind and rain, and the size is as small as possible. The normal protection level should not be lower than IP54, and the stability and reliability of the working platform should be high.

4. Anti-jamming capability of infrared temperature measurement. In high altitude areas, the sunlight is strong, and the infrared imager inside the equipment is required to be a long-wavelength thermal imager. This can avoid the illusion of heat caused by solar reflection, so as to quickly determine the operating status of the equipment. The mid-band and segment-band thermal imagers are not suitable for plateau detection.

5. The accuracy of optical and infrared imaging. Photographic and video recording of the visible light of the pod is required to achieve pin-level imaging at a distance of about 30 meters from the line. The resolution of the infrared temperature measurement image should not be lower than 320×240.

To sum up, the principle of selection of high-flying airborne pods should at least meet the following requirements: i) Working altitude above 4,500 meters; ii) Working tolerance temperature -20 ~ 55 °C; iii) Work platform stability and reliability is good; iv) Equipped with high-sensitivity long-wavelength infrared thermal imager, and effective pixels ≥ 320 (H) × 240 (V); v) Visible light reaches 30 times zoom.

Comparison of Main Pod Equipment

According to the above selection requirements, the main pod manufacturers in the country are selected for comparison. The main performance indicators are shown in Table 3.

By comparison, the parameters of domestic mainstream optoelectronic pod equipment are relatively close, and the gap between other parameters is not significant except that the nominal use altitude cannot meet the line inspection requirements in Yunnan. By comprehensive in other dimensions, purchase prices, after-sales service, application performance and other factors, Another-shore-thought-essence SkyEye3X photoelectric pods are selected for flight tests.

Selection of other Optional Aircraft Patrol Equipment

Other aircraft patrol equipment mainly includes digital cameras, anti-shake telescopes, laptop computers, flight helmets and other equipment. Because there are many different types of equipment, and their values are relatively low, the main factors to be considered, besides the technical parameters that need to be met in normal use, are the abilities to cope with adverse environmental conditions and their reliability.

Verification of the Test Flight

Under the comparison results and selection of major equipment, the first manned helicopter line inspections were carried out at high altitude on the 220kV Fujian Line (the highest altitude is 4291 meters) and the 500kV Jiantai Line (the highest altitude is 3875 meters) of Yunnan Power Grid. The pilot flight is carried out in four stages: air-flight, on-board airborne equipment, weighted test flight and manned flight test. The main features are the plateau performance of helicopters, airborne pods
and other related equipment, and the matching degree with the inspection of transmission lines. High-altitude line helicopter patrol operations procedures and other technologies have been verified. The test flight and related equipment work well.

According to this research and final experiments, the following conclusions can be drawn:

1. The selection of helicopter should mainly focus on the high-altitude performance of aircraft models. At present, helicopter models commonly used in double-engine are patrolling the plateau. There is no obvious advantage over the single-engine model.

2. The higher the relative height difference of high-altitude line body, the slower the flight speed, the higher the requirements of helicopter performance. If the line is located at an altitude of over 3500 meters above sea level at an absolute elevation, then the relative height difference exceeds 20% and helicopters cannot carry out hovering inspection operations.

3. Main performance indicators of the photoelectric pods used in helicopter inspection operations at high altitudes mainly depend on the impact of their reliable working environment conditions. Generally, they require the environmental temperature and humidity, waterproofness and reliability of electronic components in harsh environments.

4. The altitude allowed for the slow flight of the AS350B3 helicopter during the inspection of high altitude overhead lines is less than 4435m; the allowable altitude for hovering is less than 3800m. For the line with small span of the tower, and the altitude difference exceeding 20%, The line, the helicopter cannot meet the inspection requirements.

| Product Model Specifications | Unit Required- value | Huazhong Optoelectronics HIEO-10 | Luoyang Optoelectronics WMD-1G | Another-shore-thought-essence SkyEye3X | Keyi Optoelectronics KS-H | Longdong Optoelectronics ZD-SS |
|-----------------------------|---------------------|----------------------------------|--------------------------------|---------------------------------------|--------------------------|-----------------------------|
| Visible light detection effect | Minimum length of the pin-level defect can be clearly reflected at a distance of 50m from the target. | mm | 10 | 3 | 10 | 10 | 10 |
| Infrared detection effect | The absolute error of the temperature when the inspection distance is ≥50m | K | ≤2 | ≤2 | ≤2 | ≤2 | ≤2 |
| | The relative temperature difference when the inspection distance is ≥50m | K | ±0.5 | ±0.5 | ±0.5 | ±0.5 | ±0.5 |
| Size | Ball diameter | mm | ≤400 | 380 | 380 | 330 | 340 | 355 |
| | Optoelectronic pod height | mm | ≤550 | 550 | 546 | 480 | 420 | 445 |
| | Above height of optoelectronic pod mounting surface | mm | ≤50 | 0 | 0 | ≤40 | 40 | 95 |
| Use environment | Altitude | m | ≥4500m | 3500 | 3000 | 4000 | 3000 | 3500 |
| | Operating temperature | ºC | -20~+55 | -45~-+55 | -20~+55 | -45~-+55 | -20~+55 | -40~+55 |
| | Storage temperature | ºC | -20~+65 | -45~-+70 | -20~+65 | -45~-+80 | -20~+65 | -60~+70 |
| | Relative humidity | % | ≤90 | ≤90 | ≤90 | ≤95 | ≤90 | ≤90 |
| | Photoelectric pod protection class | — | No less than IP54 | IP65 | IP54 | IP56 | IP54 | IP54 |
| | Use condition under rain and snow | Light rain (snow) | Satisfy | Satisfy | Satisfy | Satisfy | Satisfy | Satisfy |
| Reliability | Mean time between failures (MTBF) | h | ≥300 | 1500 | 3000 | 300 | 500 | 400 |
| | Continuous working time | h | ≥8 | 20 | 8 | 8 | 8 | 8 |
| | Level of core components including circuit core components, chips, motors, angle sensors, slip rings, etc... | — | Industrial and the above | Above industrial level | Above industrial level | Above industrial level | Military grade | Military grade |
| | Infrared cooler working hours | h | ≥2000 | 3000 | 3000 | 8000 | 5000 | — |
| Visible camera performance | HD camera effective pixels | — | ≥1920(H) | 1920×1080 | 1920×1080 | 1920×1080 | 1920×1080 | 1920×1080 |
| | optical zoom | times | ≥30 | 40 | 30 | 30 | 30 | 30 |
| Thermal imaging camera performance | sensor type | — | Relegration | 640×512 | 640×512 | 320×240 | 640×480 | 1024×768 |
| | Effective Pixels | — | ≥320 (H) | 640×512 | 640×512 | 320×240 | 640×480 | 1024×768 |
| | Short focal length cooling type | mm | ≤50 | 18 | 25 | 39 | 50 | 75 |
| | Long focal length cooling type | mm | ≥150 | 250 | 200 | 174 | 200 | Nonrelegration |
| | Thermal sensitivity (NETD) | mk | ≤30 | 25 | 30 | 25 | 25 | 50 |

**Summary**

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By equipment selection research, we used the helicopters and airborne pods that determined by type selection to conduct actual inspections on the transmission lines of some high altitude areas in Yunnan for the first time, and completed the related line patrol test of flight operations. The goal of full coverage of helicopter patrol operations for high altitude line 220kV and above voltage classes in Yunnan was achieved. For limitations of the helicopter model, airborne equipment, pilots, and inspectors in the high-altitude helicopter patrol operations, the fine operation mode of helicopter hovering cannot be implemented for lines in special locations. Therefore, it is necessary to further deepen the relevant research.

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