THE MECHANISM AND EXPERIMENTAL STUDY ON THE INTERFERENCE OF HIGH VOLTAGE LINES TO NAVIGATION SYSTEM

L.J. FAN[†‡], X.C. PAN[†], Z.X. HUANG[†] and X.D. ZU[†]

[†]ZNDY, School of Mechanical Engineering, University of Science and Technology, Nanjing 210094, Jiangsu, China.
[‡]Special equipment inspection institute, Hefei 230000, Anhui, China.
Pxc_nust@163.com

Abstract— This essay conducts the mechanism analysis and experimental study on the interference of high voltage lines to the navigation system of UAV and shows that the essence of the interference is that air becomes corona plasma after the ionization under high voltage. In addition, when GPS signals pass through this area, some frequency channel will be absorbed. Therefore, the propagation of electromagnetic waves is prevented. The UAV tries to get GPS positioning signal by flying through high voltage area in a low height, resulting in the loss of GPS signal received by the navigation system. Through the measurement and comparison of the electromagnetic wave spectrum traveled through corona plasma, the corona plasma's absorbing of electromagnetic wave is observed.

Keywords—high voltage line; corona plasma; electromagnetic wave; refraction resonance; absorption prevention.

I. INTRODUCTION

The altitude of ultralow altitude UAV is between 0 and 100m and such UAV is widely used in agricultural plant protection, power line patrol and other fields. There exists a large number of lines whose high voltage range, from several to hundreds of kVs, may cause serious interference to the navigation system of UAV. This can lead to the loss of GPS data of the navigation system and accidents and it might even hit the transmission lines and insulated terminals causing a serious electric accident (Liu *et al.*, 2011; Chen *et al.*, 2008; Yin *et al.*, 2009).

The interference of high voltage line to the GPS system of UAV draws the attention of many scholar and technological personnel and they focus on the study on the mechanism of interference and the protection. At present, the commonly accepted explanation is that the high voltage lines generate strong electromagnetic radiation field and the radiated electromagnetic field interacts with the UAV navigation system through coupling, which leads to the error of navigation system (Zhang *et al.*, 2011; Wu *et al.*, 2009). However, such explanation does not explain the phenomenon that UAV does not interfered while flying above the electrical lines higher than the high voltage line.

Theoretically, the frequency of electromagnetic radiation is very long and it is difficult to slot coupling (Liu *et al.*, 2000; Liu *et al.*, 2008; Xiao *et al.*, 2007) with the navigation system of UAV. Through the generation and diffusion of corona plasma, this essay believes that the essence of high voltage line's interference to UAV is that air is ionized under high voltage to form a plasma. The plasma has a strong shielding effect on the GPS signal transmitted by the satellite causing the loss of signal of the navigation system (Das, 2017). Meanwhile, through the experiment of receiving GPS navigation data while the UAV flies through high voltage line area in low attitude and the measurement and comparison of the electromagnetic wave absorption spectrum while electromagnetic wave through the corona plasma, it proves the absorption of electromagnetic wave by corona plasma.

II. THE GENERATION AND DIFFUSION OF CORONA PLASMA

Due to the high voltage electric field, the air is ionized and generates corona plasma. Because the mass of the positive charge in the corona plasma is larger, the motion is slow, and the range of motion is much smaller than that of the electron. Therefore, the charged particles in this paper mainly refer to the electron (Dey, 2017).

When the charged particle is generated, it will move under the action of electric field and magnetic field, and its motion is very complicated. Considering the effect of magnetic field is much smaller than that of electric field, which is:

$$\vec{E} >> \vec{v} \times \vec{B} \qquad (1)$$

Where $\vec{E}, \vec{v}, \vec{B}$ respectively refer to electric field intensity, charged particle velocity and magnetic field intensity and the effect of magnetic field on the motion of charged particles can be ignored. Therefore the problem can be simplified to the motion of charged particles in an electric field. Then the corona induced by this motion is discussed.

It is assumed that the electric field on the surface of the conducting wire is constant and equal to E_c

$$E_c = \frac{U}{r_0 \ln \dfrac{2h}{r_0}} \qquad (2)$$

Where h refers to the lead height, U the

voltage of the lead and r_0 the semi-diameter of the lead. h is much greater than the semi-diameter of lead r_0, therefore the electric field intensity E in the space near the conductor is similar to the electric field of coaxial cylindrical capacitor，so:

$$E = \frac{U}{r \ln \frac{R}{r_0}} \quad (3)$$

Where R refers to the inner radius of coaxial cylindrical capacitor. So:

$$Er = \frac{U}{\ln \frac{R}{r_0}} \quad (4)$$

This is constant, then:

$$Er = E_c r_0 \quad (5)$$

Therefore the ion speed is:

$$v = \frac{dr}{dt} = kE = kE_c \frac{r_0}{r} \quad (6)$$

The formula above can be rewritten as follows:

$$dt = \frac{rdr}{kE_c r_0} \quad (7)$$

Integrating on half cycle and considering $r_{max} \gg r_0$, the formula above can be rewritten a

$$r_{max} \approx \sqrt{kTE_c r_0} \quad （8）$$

put $T = 0.02s$, $r_0 \approx 1.25cm$, $k = 1.8 \frac{cm/s}{V/cm}$, $E_c \approx 3MV/cm$ into the formula above, so $r_{max} = 2.2m$.

As it is seen, the effective diffusion distance of charged particles is very large. After the charged particles are generated, diffusion escape and compound disappearance happen, meanwhile a new plasma is formed by the ionization of the air in the electric field, and the dynamic equilibrium is reached forming stable distribution of plasma corona region.

III.SCATTERING OF ELECTROMAGNETIC WAVE BY CHARGED PARTICLES

The plasma corona region will obviously produce refraction and reflection of electromagnetic wave, which will affect the propagation of electromagnetic wave. The propagation of electromagnetic wave in charged particles can be analogous to the propagation of electromagnetic wave in a conducting medium and the propagation constant of electromagnetic wave in conductive medium is

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} \quad (9)$$

where ω refers to angular frequency, μ permeability, ε dielectric constant and σ conductivity. The development of the formula above concludes an attenuation constant

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}(\sqrt{1 + \frac{\sigma^2}{\omega^2\varepsilon^2}} - 1)} \quad (10)$$

and a phase shift constant

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}(\sqrt{1 + \frac{\sigma^2}{\omega^2\varepsilon^2}} + 1)} \quad (11)$$

As it is seen, the amplitude attenuation and phase shift will occur when the electromagnetic wave propagates in the charged particles and , so that the amplitude of the GPS signal is weakened or the error occurs.

IV. EXPERIMENTAL VERIFICATION

A. Experimental arrangement

The experiment can be divided into two parts, which respectively test the corona plasma shielding effect to GPS navigation signal from satellite and the absorption spectrum to electromagnetic wave causing by corona plasma. The framework of the control system of UAV is:
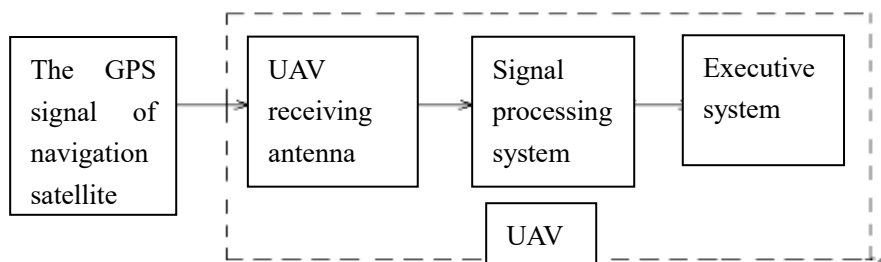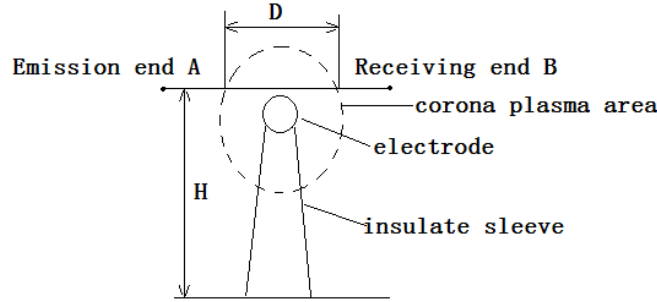

Figure 1. The framework of the control system of UAV.

Table 1. The statics of data losing of 10 flights.

Time	12:35:58	12:35:59	12:35:60	12:36:01	12:36:02	12:36:03
Nº. of valid read data	4	3	3	0	4	8
Nº. of data lost	4	5	5	8	4	0

Figure 2. Emission-absorption spectrum text experiment.

After the GPS signal from navigation satellite is accepted by UAV and receiving antenna, it is sent to executive system by signal processing system and then the cruise mission in various locations is completed. Therefore the receiving of GPS signal by navigation satellite is a key point. Once this signal is lost, the UAV will not complete given cruise mission.

①Shielding of high voltage transmission line to GPS data of UAV

Made the UAV flied in a low attitude. To ensure safety, make UAV respectively fly below and above the 220kV industrial transmission line. Moreover, made the UAV flied at a vertical distance of 5m and 10m respectively with a GPS signal frequency of 1268MHz. The result was:

While flying below the line, the UAV lost control for 8 times. The GPS date in the black box showed that the data during the losing-control period was lost. The part of the data when the UAV flied below the lines from 12:35:58 to 12:36:03 were shown in following form. The data were read 8 times per second in the experiment:

Meanwhile, it was also found that the time of missing data was continuous.

The out-of-control situation was not found in the experiment while flying over the lines and there was not losing of GPS data in the black box.

②Absorption of electromagnetic wave by plasma

The GPS signal comes from positioning satellite and it travels in the form of electromagnetic wave. The plasma has the effect of attenuation and phase shift on the electromagnetic wave. Therefore, through observing the incident electromagnetic wave absorption spectrum, it proves the interference and shielding of GPS signal produced by corona plasma generated by high voltage line. The experimental arrangement was like:

Electric pulses from a pulsed source were transmitted through a broadband antenna and then electromagnetic wave were transmitted, the electromagnetic wave traveled through the corona plasma generated by electrode loaded 200kV direct current high voltage, and the received signal was measured at the receiving end by the same broadband receiving antenna. Through the comparison of emission spectra and receiving spectra, the absorbing of electromagnetic wave by corona plasma was observed. In order to obtain enough wide frequency range bandwidth, the electric pulses wave in time domain is double exponential wave, the experimental principle is shown in Fig. 2.

Assume that in Fig. 2 the corona plasma area is nearly circular, keeping the Link Lines of emission-reception parallel to ground. Obviously, changing the height H between the transmitting end and the ground can change the distance D that electromagnetic wave travel in corona plasma, because it is related to the distance for electromagnetic wave attenuation when it travels through corona plasma, and if plasma have shielding and interference on the electromagnetic wave, the receiving spectrum will be different. In the experiment, the minimum height H is about 1.5m, the receiving spectrum was read when height H was raised per 15cm, Fig. 3 is the emission spectrum. The Fig. 4 to Fig. 7 are respectively the receiving spectrum when the heights are1.65m,1.8m,1.95m,and 2.1m.The same attenuator is used in various heights

It can be seen from Fig. 3 and 7 that the plasma has obvious shielding for electromagnetic wave within the frequency between 320MHz and 900MHz. Meanwhile, the receiving spectrum is obviously different at different distance.
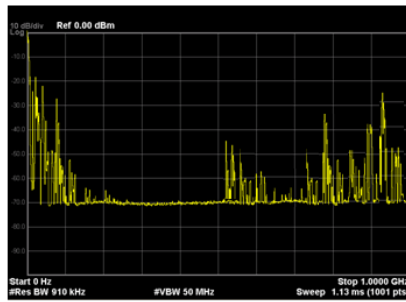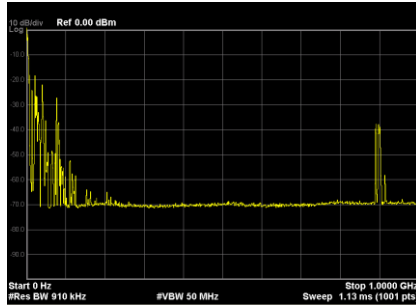
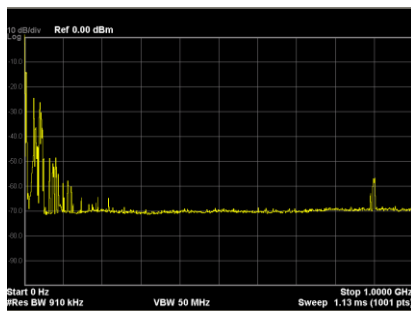**Figure 3**. Emission spectrum.

Figure 4. Receiving spectrum at H=2.1m.

Figure 5. Receiving spectrum at H=1.95m.
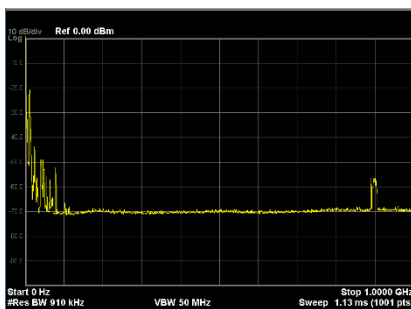

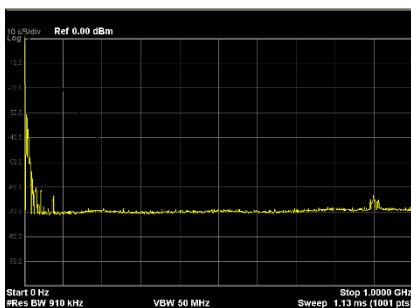**Figure 6**. Receiving spectrum at H=1.8m.

Figure 7. Receiving spectrum at H=1.65m.

B. Experimental analysis

It can be seen from the receiving experiment on GPS receiving data, the loss of receiving data happens when UAV flies below high voltage line area and there is not such situation when it flies above the high voltage line. Because the high voltage line can generate corona plasma, it proves that the loss of GPS navigation data is related to the shielding of electromagnetic waves by plasma. It is worth noting that, even when the UAV flies through the high voltage line, there is no interference of receiving data, which in turn confirms the statistical characteristics of the corona plasma fluctuations.

To explain with the experiment of emission spectrum and receiving spectrum where within the frequency scope between 320MHz and 900MHZ, the plasma has obvious interference and shielding to electromagnetic wave and the phenomenon of interference and shielding from plasma can be explained on the attenuation of electromagnetic wave and phase shift. In the formula (10) and (11), it refers to attenuation and phase shift of electromagnetic wave propagating in plasma. Due to different incident angles, the plasma has different reflection and refraction on the electromagnetic wave. So the electromagnetic wave amplitude and phase in the plasma region are different. Meanwhile, due to different atmospheric conditions, altitude and air humidity, the physical characteristics such as plasma density and equilibrium distribution are different. Therefore, it is quite difficult to get the relationship between attenuation factor, phase shift factor and the incident angle accurately. However, it proves that the shielding and interference of electromagnetic wave by corona plasma exists.

V. CONCLUSIONS

This essay discusses the conditions where high voltage lines generate corona plasma and analyzes diffusion of plasma in the electrical field of high voltage line. Through the GPS signal obtained by UAV while flying below and above the high voltage lines respectively, it finds that the loss of GPS navigation date happens when the UAV flies below the lines and not when it flies over the limes. Through the measurement and comparison of the electromagnetic wave spectrum while the electromagnetic wave traveled through the corona plasma, the shielding and interference effect of corona plasma on electromagnetic wave is observed. This proves that the signal loss of UAV navigation system is because air is ionized under high voltage environment into corona plasma, which has strong shielding effect on the GPS signal sent by satellites.

REFERENCES

Chen, X.B., Y.L. Ma and Z.J. Xu, "Research on Transmission-lines-cruising technology with the Unmanned Aerial Vehicle", *Southern Power System Technology*, **2(6)**, 59-61 (2008).

Das, U.J., "Heat and mass transfer of Mhd visco-elastic oscillatory flow through an inclined channel with heat generation/absorption in presence of chemical reaction", *Latin American Applied Research*, **47(2)**, 47-52 (2017).

Dey, D., "Hydromagnetic oldroyd fluid flow past a flat surface with density and electrical conductivity stratification", *Latin American Applied Research*, **47(2)**, 41-45 (2017).

Liu, S.K., J.M. Fu and Y. S. Chen. "Numerical. Analysis on slot coupling effects of FREMP". *Journal of Microwaves*, **16(2),** 182-186 (2000).

Liu, X. F., Z.Y. Gan and X.W. Zhang, "Calculation of active interference in Aeronautical Radionavigation Stations caused by UHVAC Transmission Line", *Power System Technology*, **2**, (2008).

Liu, X.F., H. Yin and X. Wu, "Test and analysis on effect of high voltage transmission lines corona radio interference and scattering to GPS signal", *High Voltage Engineering*, **37(12)**, 2937-2944 (2011).

Wu, X., N. Li and G.Z. Zhang, "Limits and design control of radio interference for 1000KV AC transmission lines", *High Voltage Engineering*, **8**, 1791-1795 (2009).

Xiao, D.P., W., P. He and J. Xie, "Study on corona discharge characteristic of high voltage transmission line and calculation of its electromagnetic radiation field", *Power System Technology*, **31(21)**, 52-55 (2007).

Yin, H., X.H. Zhang and X.W. Zhang, "Interference analysis to aerial flight caused by UHV lines using airborne GPS", *Geomatics and Information Science Journal of Wuhan University*, **34(8)**, 774-777 (2009).

Zhang, Y. M., G.Z. Zhang and B.Q. Wan, "Electromagnetic environment of 1000KV AV single-circuit compact transmission lines", *High Voltage Engineering*, **37(8)**, 1888-1894 (2011).