Simulation of Wear Particles on Electric-field Intensity Distribution Around Conductors

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Abstract

Taking LGJ150/25 as the study object, a finite element simulation model of space around the wire with fretting wear particles was built, which was used to study the influence of the size, the shape and the distribution of the fretting wear particles on electric-field intensity distribution around transmission wires. It is of important the theoretical significance and application prospects for this work to reduce the energy loss and the electromagnetic interference. The simulation result are as follows: in the case of the same loading voltage, when particles is higher than wire maximum diameter, the maximum field intensity around the wire is sharply increased; Along with increase of the radius of curvature of the particles, the maximum field intensity will be reduced; The degree of irregularity of particles distribution is larger, the maximum field intensity value is bigger. According to the relationship between the field intensity distribution and the corona inception voltage, it can be concluded that with the increase of the maximum field intensity, the corona inception voltage can be reduced, so corona inception voltage will be directly affected by fretting wear particles.

Keywords: Fretting wear, Emulation, corona inception voltage, corona inception field

1. Introduction

With the development of the electrification of the railways, the transmission capacity and the transport distance grow rapidly, and the electric transmission lines of large capacity, long distance and high voltage levels have been put into operation in success. With the increasing of the conveying voltage the electric field intensity around the wire rises, corona discharge is generated while the value of the electric field intensity reaches to the ambient air breakdown voltage. Corona discharge can produce a lot of adverse effects [1]. The factors that influence corona discharge of the wire have been systematically researched by many scholars, the key point of their researches was concentrated on the influence of external factors on corona discharge, and which concluded that the corona loss could be reduced by lessening surface roughness of wire [3], [4]. But the research about the influence of the wear particles produced by wind load vibration in strands, on corona discharge of wire is little. A mass of experiments demonstrated that, under the wind load vibration, overhead transmission conductor abraded among the inner strands, and between the wire and the wire holder [5], [6]. The wear particles in the wire overflowed out to the surface and attached to the surface, which affects the surface roughness of the wire, so it is inevitable to affects the field intensity distribution around the wire [7]. Ansys, finite element simulation software was applied in this paper to analyze the influence of the size, the shape and the distribution of the wear particles on the field intensity distribution. It has practical significance on analyzing influence of the wear of the wire on the corona discharge.

2. Conductor Corona Discharge

Corona discharge is a kind of self sustaining discharge phenomenon in non-uniform electric field [8], [9]. It would produce a great many of energy loss, in addition to that, it can also produce electromagnetic interference, audible noise and harmful chemicals which would affect people's normal life. Many factors may affect corona discharge, in addition to the arrangement of transmission conductor, the height above the ground, the air humidity and the atmosphere,

the surface condition of conductor itself would also affect it greatly. A large number of scholars have proved that the roughness of conductor surface was an important factor which affects conductor corona discharge [10], [11].

Under a certain on-load voltage, enough electric field intensity would be generated around the wire, which would lead to electron avalanche by free electrons around the wire and then overall corona discharge would be produced. Meanwhile, the biggest point of the electric field intensity in the conductor surface is the starting point of corona discharge, the field intensity is the corona inception field intensity and the corresponding voltage is the corona inception voltage.

FW Peek was the first person who deduced the empirical formula of corona inception field intensity and voltage through experimental data.

$$E_c = 30.3 m \delta (\frac{1+0.298}{\sqrt{r\delta}}) kV/cm \tag{1}$$

And in this formula, m---surface roughness coefficient; r---wire radius; δ---relative density of air

As formula (1) showed, start from the angle of gas discharge and by theoretical calculation, Han Shaowei [12] et al got the law that corona inception voltage changed with mitotic count, atmospheric temperature, atmosphere and some other factors. The calculating result was in accordance with the empirical formula built by FW Peek, which testified the validity of the formula.

From formula (1), we knew that corona inception field intensity wasn't a constant. In order to make conductor corona discharge be self-sustaining, the field intensity on the surface of wire should be big enough and the space being a certain distance away from the wire also need to be big enough. The abrasive particles attaching to the surface of the wire leaded to the appearance of some space with a short local radius around the wire, which made the distribution of the field intensity around the wire change greatly. The distributions of the field intensity around the wire affected the corona inception voltage of the wire directly. In order to maintain certain field intensity around the space, the wires which field intensity decreased faster must be of stronger field intensity to make the discharge self-sustaining.

3. The Simulation Analysis of Wear Debris to Space Field Intensity Distributions Around the Wire

Wire LGJ150/25 was taken as the analysis object in this paper, and the basic parameters of the wire was shown in Table 1.

Table 1. The specification of LGJ150/25（GB1178-83）

Nominal cross section (mm^2)		Calculating section (mm^2)		Number of single wire		Diameter of single wire (mm)		External diameter (mm)
Aluminum stranded conductor	Steel cored wire	Aluminum stranded conductor	Steel cored wire	Aluminum stranded conductor	Steel cored wire	Steel strand	Steel cored wire	
150	25	148.79	24.23	26	7	2.7	2.1	17.1

Assumptions have been set about the wires described in Table 1:
(1) Assuming that wires were in infinite space, and ignoring the influence of the earth and the surrounding environment to the electric field distributions.
(2) Assuming that the transmission conductor was of indefinite length, the wire is an equipotential body and the surface of the wire was equipotential. The voltage drop has been ignored.
(3) The influence of the air humidity and temperature were not taken into consideration, and the air dielectric constant is assumed as $\varepsilon = 1.006$.

According to the above assumptions, the model of the distributions of electric field around the wire under certain voltage could be simplified into two-dimensional static analysis model. Taking the surface profile of the wire LGJ150/25 as the basis, the analysis model of smooth wire finite element could be constructed as shown in figure 1[13]. If take the air area around the wire with the radius D=0.4m as the analysis area of electric field intensity, the specific model and meshing could be constructed as shown in figure 2. The paper analyzed it from three aspects of abrasive particles, i.e. the size, the shape and the distributions of abrasive particles.
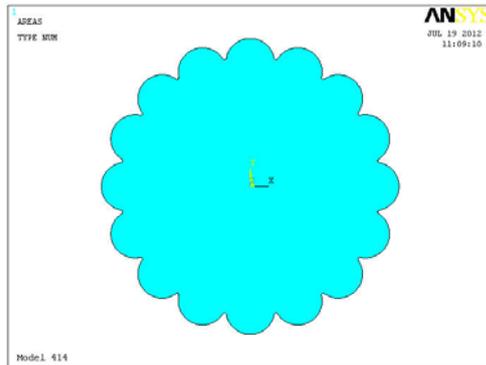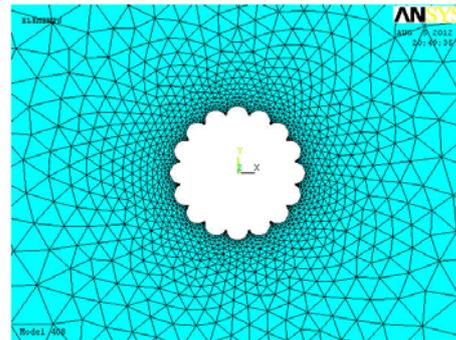

Figure 1.The diagram of the wire surface profile

Figure 2. The meshing of wire model

3.1. The Influence of the Size of Abrasive Particles on the Field Intensity Distributions

The simulation model set cone shaped abrasive particles as the research object, and abrasive dusts were set among the wire strands on the surface. On the basis of the same cone diameter d, six kinds of the abrasive particle heights were set as 0.2mm、0.4mm、0.6mm、0.8mm、1.0mm and 1.2mm. The height of the abrasive dusts which was 0.8mm among the wire strands was in parallel with the maximum external diameter. The abrasive wire model with the height of 1.2mm is shown in figure 3, and the on-load voltage was 35kV. Figure 2 is the simulation value of the maximum and minimum field intensity of the air around the wire on the condition of six kinds of abrasive particles and the smooth conductor (0mm).
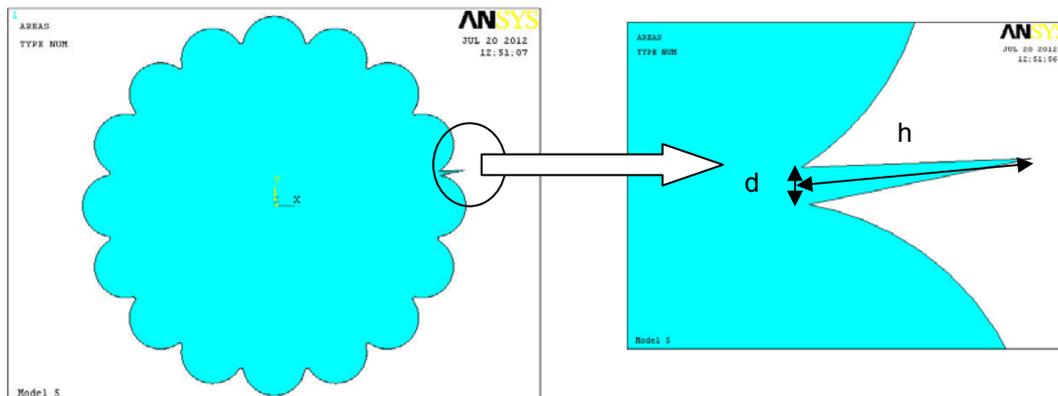

Figure 3. The diagram of the size model of abrasive particles

Table 2. The Influence of the Height of Abrasive Particles on the Maximum
and Minimum Field Intensity

The height of abrasive particles (mm)	0	0.2	0.4	0.6	0.8	1.0	1.2
Min(V/m)	6745.3	6769	568.051	287.262	29.242	16.917	14.863
Max(10^5V/m)	8.600	8.566	8.589	8.589	13.288	23.683	34.697

From table 2, it could be found that different heights of abrasive particles affected the electric field distributions around the wire greatly. When the height of abrasive particles increased from 0mm to 1.2mm, the minimum field intensity decreased from 6745.3 V/m to 14.863 V/m, but the maximum field intensity increased from 8.6×105 V/m to 34.697×105 V/m. The height 0.8mm was the inflection point of change, when the height was shorter than 0.8mm, i.e., shorter than the maximum external diameter, the maximum field intensity didn't change at all while the minimum field intensity decreases rapidly with the increasing of the abrasive particle height. When the height of abrasive particles parallels with the maximum external diameter (the height of abrasive particle is o.8mm), the field intensity rises immediately and increased with the amplifying of the size of abrasive particles sharply. On the other hand, the minimum field intensity decreased immediately and decreased with the increasing of the height of abrasive particles.

From the relationship between corona inception field intensity and electric field distributions described above, it can be got that under the same air condition, with the increasing of the maximum field intensity, the corona inception voltage decreased gradually when the attenuation gradient of the field intensity meets the requirements. By comparing the data in table 2, there is no obvious influence to the corona inception voltage from abrasive dusts when the abrasive dusts height was shorter than the maximum external diameter of the wire. When the abrasive dusts height was longer than the maximum external diameter, the corona inception voltage would decrease sharply with the increasing of abrasive dust height. That is to say, wires would produce the corona discharge phenomenon when it was in a relative low on-load voltage.

Therefore, in order to reduce the influence of abrasive particles heights to the corona discharge, we should try to avoid the existence of abrasive dusts that were longer than the maximum surface external diameter in actual running of the wire. Also, we could clean the wire surface regularly.

3.2. The Influence of Curvature Radius of Abrasive Particles to Field Intensity Distribution

The shape of the research object abrasive particles has been assumed to be oval. Then set the major semi-axis a be the same and the minor axis b as 0.2 mm、0.4 mm、0.6 mm、0.8 mm、1.0 mm and 1.2 mm respectively. Longer the minor axis was, larger the top curvature radius of abrasive particles was. The wire model was shown as figure 4: the on-load voltage was 35kV, the calculating simulation value of the maximum and minimum field intensity of the air around the wire was shown in table 3.
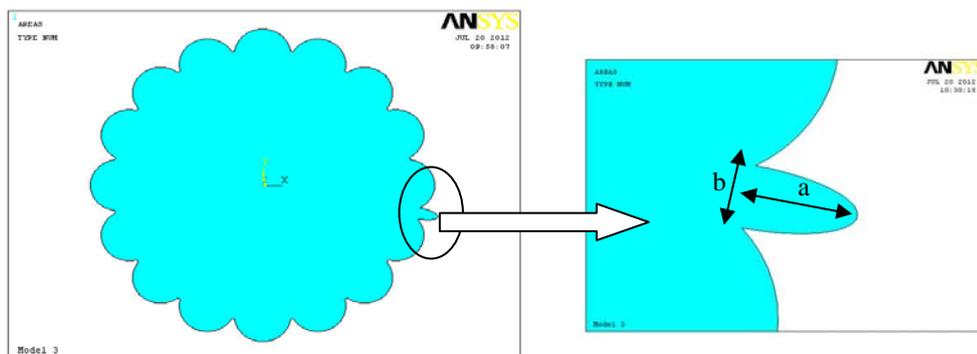
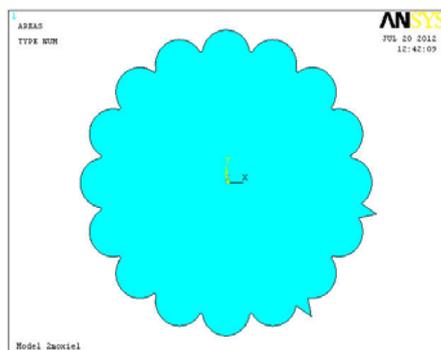

Figure 4.The diagram of the oval abrasive particles model

Table 3. The influence of abrasive particle shapes on the maximum
and minimum field intensity value.

| The length of minor axis	0.2	0.4	0.6	0.8	1.0	1.2
Min(V/m)	15.915	423.89	1798.1	6550.7	6490.6	6424.8
Max(V/m)	3224700	2261200	1815700	1592000	1445300	1341200

Table 3 listed the maximum and minimum field intensity of the air around the wire, which contained different top curvature radius of abrasive particles. From the data in the table it could be found that with the heightening of the minor axis of oval abrasive particles, i.e, the increasing of the surface curvature radius of abrasive dusts, the maximum field intensity of the air around the wire decreased gradually, while the minimum field intensity increased gradually. The changing gradient of the field intensity increased gradually.

According to the previously obtained relationship between the maximum field intensity and the corona inception voltage, and by contrasting the data in table 3 it could be found that the maximum field intensity around the wire decreased gradually, while the corona inception voltage increased gradually with the increasing of the top curvature radius of abrasive dusts.
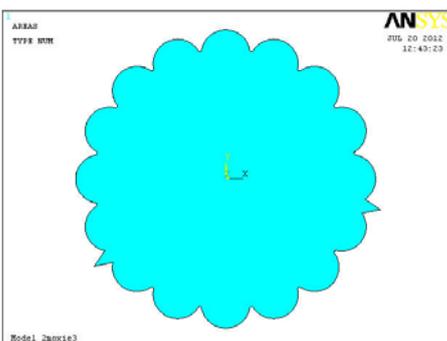
Therefore, in order to increase the corona inception voltage of the wire and decrease the corona loss of the wire, the wire could be optimized from the wear mechanism and material aspects to avoid the appearance of sharp micro abrasive wears in actual operation of the wire.
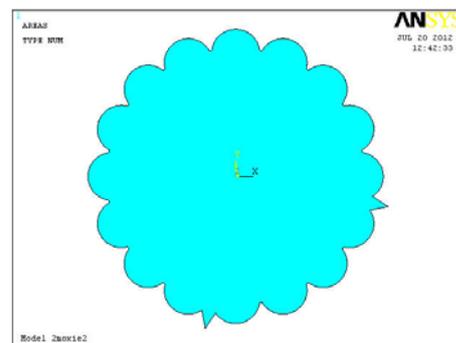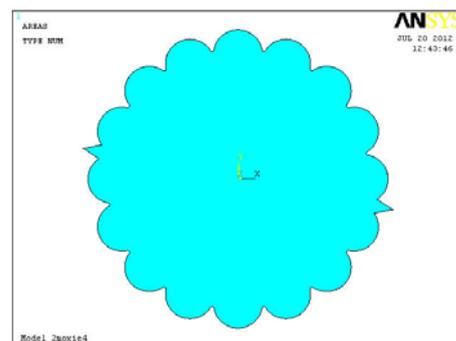

(a) Abrasive particles with 2 strands as the interval	(b) Abrasive particles with 4 strands as the interval
(c) Abrasive particles with 6 strands as the interval	(d) Abrasive particles with 8 strands as the interval

Figure 5.The diagram of abrasive particle distribution

3.3. The Influence of Abrasive Particle Distributions on Field Intensity Distributions

Abrasive particle distribution referred to the location of the abrasive particles that attached on the surface of the wire. That was the location in the stands of the surface wire. It could be assumed that there were two abrasive particles in one cross-section of the wire. For the steel reinforced aluminum conductor LGJ150/25, with 16 strands aluminum wires in the outmost layer, the interval growth among the abrasive particles is 2 strands. There were 4 distribution modes, i.e., 2, 4, 6 and 8 wire strands. The on-load voltage was 35kV and the calculating simulation value of the maximum and minimum field intensity of the air around the wire is shown in Table 4.

Table 4 listed the maximum and minimum field intensity of the air around the wire in the above four ways of abrasive particle distribution. From the data in the table it could be found that the minimum field intensity differs little in different distribution models. The numerical value of the maximum field intensity is large only when the space between abrasive particles is 2 strands. That is to say, larger the non-uniformity degree of the abrasive particle is, larger the maximum field intensity value is, and larger the changing gradient of the field intensity is.

According to the previously obtained relationship between the maximum field intensity and the corona inception voltage and by contrasting the data in table 4 it can be found that the maximum field intensity around the wire increases with the increasing of the non-uniformity of the abrasive dusts distribution in the wire surface. And then it will cause a gradual decrease of corona inception voltage of the wire.

Therefore, in order to increase the corona inception voltage of the wire and decrease the corona loss of the wire, the local concentration of abrasive dusts should be avoided.

Table 4.The influence of two different abrasive particle distributions on the maximum and minimum field intensity

Abrasive particle distribution	Abrasive particles with 2 strands as the interval	Abrasive particles with 4 strands as the interval	Abrasive particles with 6 strands as the interval	Abrasive particles with 8 strands as the interval
Min(V/m)	6351.5	6535.9	6560.8	6542.4
Max(V/m)	1520800	1486400	1487700	1487400

4. Conclusion

The simulation analysis results showed that different sizes, shapes and location distributions of the micro wear abrasive particles greatly affected the field intensity distribution of the space around the wire. Furthermore, there are some rules as follows:

1) The existence of micro abrasive particles affects the field intensity distribution of the space around the wire to some degree.

2) The influence of abrasive particles to the field intensity of the space around the wire isn't obvious when the abrasive particle height is shorter than the maximum external diameter of the wire. On the contrary, when the abrasive particle height is longer than the maximum external diameter of the wire, the maximum field intensity of the space around the wire increases sharply and the corona inception voltage drops sharply with the increasing of abrasive particle height. However, the gradient of the field intensity always increases with the increasing of abrasive particle heights.

3) With the increasing of the top curvature radius of abrasive particles, the maximum field intensity around the wire decreases gradually. Meanwhile, the corona inception voltage rises, the minimum field intensity increases gradually and the changing gradient of the field intensity increases gradually.

4) With the increasing of the non-uniformity of the abrasive particle distribution, the maximum field intensity of the space around the wire increases. Meanwhile, the corona inception voltage is low and the changing gradient of the field intensity increases as well.

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