Electrode Conditioning Characteristics in Vacuum Based on Discharge Current

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Abstract: In order to develop vacuum circuit breakers (VCBs) in higher voltage level, it is very important to clarify the electrode conditioning characteristics. In this paper, we investigated the impulse spark conditioning in non-uniform field with changing discharge current in a vacuum. Experimental results revealed that the discharge current greatly influenced the spark conditioning characteristics of CuCr electrode, the finally obtained BD voltage, the rising process of BD voltage, and the electrode surface.

Keywords: Vacuum, Spark Conditioning, CuCr, Discharge Current

1. INTRODUCTION

A vacuum is noticed as an environment-friendly medium for electrical insulation and arc quenching[1]-[4]. In order to develop higher voltage vacuum circuit breakers (VCBs), clarification of the electrode conditioning characteristics is necessary because the conditioning effect is a key technique to improve the insulation performance of VCBs[5]-[8].

In this paper, we quantitatively investigate spark conditioning of CuCr in non-uniform field by changing discharge current. We discuss how the discharge current influences the spark conditioning process.

2. EXPERIMENTAL SETUP AND PROCEDURES

Fig.1 shows the electrode configuration. Negative lightning impulse voltage was applied to a rod-plane electrode. The rod electrode made of CuCr and the plane electrode made of SUS304 were used. The gap distance was d=5mm and the tip radius of rod electrode was R=2mm (non-uniformity factor: h=2.90). We investigated the conditioning effect of BD in the series of negative LI voltage applications. The voltage application procedure was up-down method. The series resistance R_S (60Ω, 2kΩ, 11kΩ, 20kΩ) was used to change the discharge current at BD. The pressure in vacuum chamber was kept at the order of 10⁻⁶ Pa.

3. MEASUREMENT RESULTS AND DISCUSSIONS

3.1 Dependence of discharge current on BD voltage after conditioning

Fig.2 shows the spark conditioning history for different series resistance R_S for CuCr electrode. In this figure, the plot at the time of no BD was omitted and 50% BD voltage (V₅₀) were indicated. In annotation, we show the front / tail time of applied voltage that depend on R_S. We found that V₅₀ after was 60Ω < 2kΩ < 11kΩ = 20kΩ. Here, two reasons are possible to explain the different final V₅₀ by R_S. One is the change of the discharge current amplitude and the other is the change of applied voltage waveforms. But from the other experimental results, we derived that the former reason is the predominant factor[9]. That is, electrode surface condition after conditioning is better in a smaller discharge current.

For considering the relation between the final BD voltage after conditioning and the each discharge energy, we introduced a parameter “charge per single BD”, which is the time integration of discharge current at single BD. The charge in vacuum chamber was kept at the order of 10⁻⁶ Pa.
BDs after conditioning. In this figure, plot indicates the $V_{BD}$ and the error-bar indicates the range from its maximum to minimum. BD field strength is the maximum field strength at breakdown.

This figure clearly shows the relationship between the final BD voltage after conditioning with the charge per BD in the spark conditioning of CuCr electrode. We found that maximum BD voltage was saturated with 250kV and maximum BD field strength was 145kV/mm when the charge per single BD is less than 1.2mC.

3.2 Relationship between the rising process of BD voltage and the discharge current

The rising process of BD voltage is very important to evaluate the conditioning effect. As an example, we investigated the rising process of BD voltage to 200kV in CuCr electrode.

Firstly, we discussed the number of voltage applications required for conditioning. From Fig.2, the number of voltage applications required for reaching 200kV is minimum for $R_s=2k\Omega$, and maximum for 20k$\Omega$. For rapid increase of BD voltage, $R_s=2k\Omega$ is the best choice in this experiment.

Secondly, we discuss injected energy required for conditioning. Fig.4 shows the conditioning history evaluated by the cumulative BD charge which corresponds to the injected energy. The cumulative BD charge required for 193kV is maximum for 60$\Omega$ with large discharge current.

Fig.5 shows the rising process of BD voltage required for reaching $V_{BD}=193kV$ in CuCr estimated by the number of voltage applications and the cumulative BD charge taking into account the charge per single BD. The charge per single BD indicated the value when the BD occurred at 193kV. This figure shows clearly the relationship mentioned above. Cumulative BD charge required for conditioning is larger when the charge per single BD is large. This result indicated that the more injected energy was used for damaging when the BD charge was large in the spark conditioning. That is, the experimental result quantitatively revealed that the injected energy into electrode contributed not only for improving but also damaging the electrode surface.

3.3 Electrode surface before and after conditioning

Fig.6 shows the tip of the rod electrode surface of CuCr before and after conditioning observed with a digital microscope ($\times 50$, $\times 2000$). In this figure, $V_{50}$ after conditioning, the number of BD ($N_{BD}$) and single BD charge at $V_{50}$ (q) the cumulative BD charge ($q_{Cum}$) were also indicated.

From Fig.6 (a), before conditioning, we found surface roughness by mechanical finish and exposition of Cu in CuCr. After conditioning, from (b) $R_s=60\Omega$ with the lowest BD voltage, electrode surface changed melting layer in whole region. From (c) $R_s=2k\Omega$, (d) $R_s=11k\Omega$ and (e) 20k$\Omega$, even though, the discharge traces were seen in the region where Cu is initially exposed and Cu changed into melting layer. However, discharge traces were seen in other region; the traces of mechanical finish remained. Especially, in case of $R_s=11k\Omega$ and 20k$\Omega$, discharge traces are very few in the part other than Cu exposition. From this result, we found that, in case of CuCr, conditioning was selectively done from the region where Cu is initially exposed and that discharge trace of other region did not contribute to improve the electrode surface. From a detailed observation of electrode surface condition, we revealed that “conditioning degree” was different according to the discharge current.
4. CONCLUSION

In this paper, we investigated spark conditioning effect under non-uniform electric field in a vacuum focused on the discharge current. As a result, we could find the following conditioning characteristics using CuCr electrodes.

(1) BD voltage after conditioning was quantified in consideration of the charge per single BD. BD voltage was saturated with 250kV and maximum BD field strength was 145kV/mm when the charge per single BD is less than 1.2mC.

(2) The evaluation of the rising process of BD voltage based on BD charge revealed that the injected energy into electrode contributed not only for improving but also damaging the electrode surface. The large discharge current more contributes to damaging the electrode surface.

(3) From a detailed observation of the electrode surface, “conditioning degree” was different according to the discharge current. In case of CuCr, conditioning was selectively done from the exposition of Cu.

5. REFERENCES


