DOI: 10.18454/PMI.2017.2.235

UDC 658.392.2:656.2

METHOD OF RESTORING STRENGTH DETERMINATION TEST

Stanislav M. APOLLONSKY[1], **Yurii V. KUKLEV**[2]
[1] *Company Ltd «Electromekhanotronika», Saint-Petersburg, Russia*
[2] *Peter the Great Saint-Petersburg Polytechnic University. Institute of Energy and Transport Systems, Saint-Petersburg, Russia*

The main requirements for an electric unit at the stages of its design, development, production and usage are described in technical specifications (TS) and standards (GOST). The electric unit should work in accordance with a specific purpose and have significant reliability, durability and safety.

The reliability and durability of electric unit significantly depends on restoring strength speed value, that is growth of breakage voltage in arc pass for eliminating repeated arc strike.

This article describes several methods of test identification of restoring strength, which were carried out at special testing laboratory units. They are described in relation to conditions of measuring the residual arc column of AC current after it reaches zero point and can be used in designing arc blowout units of low voltage.

Key words: low voltage units, arc blowout units, restoring strength, strength of residual arc column, alternate current

How to cite this article: Apollonsky S.M., Kuklev Y.V. Method of Restoring Strength Determination Test. Zapiski Gornogo instituta. 2017. Vol. 224, p. 235-239. DOI: 10.18454/PMI.2017.2.235

Introduction. In development of electric and electronic machines, first of all, it is necessary to take into account their prescribed switching capacity, which sets certain functional and technical requirements.

The main requirements are:

– temperature limit during prolonged heating;
– electrodynamic bracing during SC current;
– thermoresistance of the machine during SC current;
– switching durability matching the capacity of this machine type;
– workability of the machine.

Meeting all these requirements is one of the reasons of existence of different electric machine types.

The reliability of electric machines is provided by design of their units. The key units of electrical machines are:

• contact system having switching device;
• arc-control device;
• drive (electromagnetic unit);
• external magnetic blowout.

The last unit present not in all machines.

The assessment of machine reliability could be difficult sometimes due to lack of information on unit characteristics. In this case, we build a physical model and conduct additional tests different from sample testing. Additional tests increase economic expenditures that is why we need to assess the practicability and necessity of these tests.

To reduce expenses on additional tests we create mathematical models showing and analyzing the working process of the desired unit. However, mathematical modelling could be challenging because of complex physical process occurring in electric machines. We can take the example of processes accompanying the current zero of electric arc in switching devices. When the growth of electric line voltage in contact solution exceeds the restoring strength, it could

DOI: 10.18454/PMI.2017.2.235

lead to recurrent arc strike and cause excessive wear out of contacts [1]. Besides that with heavy current the electric arc more closely fits to insulating wall of the machine. The uneven heating of insulating wall is accompanied by mechanical tension inside this wall, which leads to deformation of magnetic blowout chute and its early wear. The research of such mechanic tensions is of concern about the deterioration of chute walls. The difficulty of this type of research lies in the size (which is small) and surface of impact these deformations.

The influence of these processes on machine reliability can be decreased with the help of vacuum units. The abrupt reduction of gas particles concentration decreases the possibility of occurrence of current carriers (electrons and ions). Thus, the electric strength in vacuum increases in 4-5 times in comparison to air at ambient pressure. Most current carriers are produced out of metallic cathode due to electron emission. When emission stops, for example, when AC current passes zero, there is no possibility for current flow and the circuit switches off [2, 4].

Two abovementioned processes happening during switching off are relevant to no-contact electric machines. In this case the electro-magnetic energy is transformed into capacitive energy instead of heat one.

The induction of external and internal magnetic field creating the magnetic blowout should provide quick escape of the arc from the contacts, especially during the last stage of arc blowout, to prevent the circuit overload because it exceeds the valid load of electric machine winding. Resulting from this the hybrid machines were introduced, especially for currents above 25 A.

There are no methods for direct measurement of restoring strength in experimental procedures. It is determined with voltage which goes through the pass between contact during the test. The need to apply the measuring voltage leads to distortion of conditions in gas-discharge channel because of the energy, which is produced in it under this voltage load. That is why any measuring method enables determining restoring strength which is to any extent differs from so-called «cold crushing strength» applied to a pass itself without any external voltage load. The degree of distortion of the measured value from «cold crushing strength» depends on the measurement method.

Let us consider some methods for measuring restoring strength which are applied for arc-blowout units with low voltage. Usually these methods allow measuring only one point of restoring strength curve in one test.

The described methods are applied to measuring the strength of residual arc column of AC and DC reaching zero value.

Restoring strength of arc column of DC free arc. At t time period the arc pass from the conductor turns into non-conductor and its voltage gradually grows (inductance decreases zero pause and promotes arcing).

If increase of arc current distance resistance, expressed as its DV u_{dv} (curve 1), advances the increase of restoring voltage u at distance (curve 2), then the arc will starve when going through zero (Fig.1).

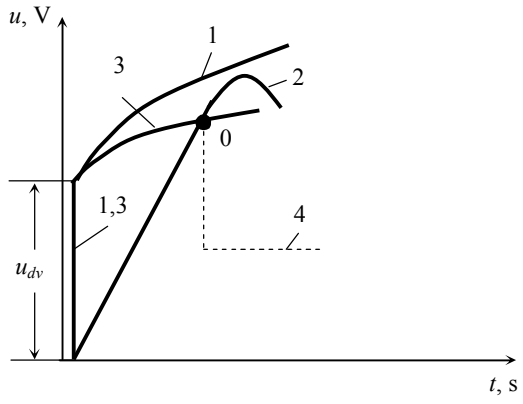


Fig.1. Conditions of AC current arc blowout

If the increase of distance resistance is slow (curve 3), then at the timepoint corresponding to 0 point the arc will strike again and the arc voltage will change (curve 4).

As a rule, the electric strength of arc distance grows faster from the start and then it increases in a slower mode. According to tests when arc current disappears the space near cathodes almost immediately has the electric strength of 150-250 V. It could be explained by presence of cathode space charge (electrons will go to anode and it will not have negative space charge). A

DOI: 10.18454/PMI.2017.2.235

cathode has positive space charge out of sluggish ions and its space becomes free from electrons. When the arc strikes for too long the electrodes will heat and significantly decrease the electric strength of cathode distance, which could be only of a few tens of volt.

For DC machines these methods are:

• Method of critical conditions: the cut off circuit has so-called critical conditions, when there is no repeated arc strike. It is created by distance restoring strength speed control [4].

• Method of creating special arc strike conditions:

a) a cut off circuit should have certain conditions under which the arc strike is stable during several half periods. The restoring strength oscillography is recorded with developing view representation of process in time [5];

b) method of impulse circuits. At certain time intervals when current passes zero a synchronizing device switches off electric power supply and applies the voltage impulse sufficient for arc discharge. By changing the voltage impulse value and time of application to distance we determine the points of restoring strength curve. The voltage impulses can be applied in pre-defined time intervals and determine in one test not a single but several points of restoring strength curve.

Methods a) and b) do not allow recording changes of restoring strength into continuous curve during single test. In such test we can determine only one point of this curve. A curve build on several points can represent only relative curve of restoring strength because the process of strength restoration in one test can differ from the same process during another test and strength value can have spread in values. If we want to have several points for building restoring strength curve, then the test should be modified in such manner that we would be able to record a set of points with simultaneous arc blowout during the same number of blowouts coupled in line into a main current circuit.

When analyzing methods of restoring strength tracing in low-voltage DC units we should note a significant factor: when current and voltage pass zero point the arcs match. Slight deflections in time can be due to inductivity of gas charge plasma.

Restoring strength of AC free arc column. The AC arc blowout units have different processes [2, 5].

The free arc appears in cut off circuit when a unit does not use any methods of arc column cooling intensification. This arc has natural heat exchange between warmed gas and environment – air in normal atmospheric conditions. When switching off low current values (5-128 A) due to significant electrodynamic forces the arc is quickly blown out from contacts and stretched behind them. The test results analysis [3, 5] showed that it leads to significant reduction of restoring strength. Under average ($I \leq 3000$ A) and high current values ($I \gg 3000$ A) the gap restoring strength greatly increases.

The dependency of free arc restoring strength form time in a range from 15-20 to 200-300 ms can be expressed as approximation formula [5]:

$$u_{\text{r.s}} = U^0_{\text{r.s}} + K_{\Sigma} t\,,$$

where $U^0_{\text{r.s}}$ is initial restoring strength in the abovementioned relative understanding of this value, V; K_{Σ} is growth of strength, V/ms.

The dependencies $U^0_{r.s} = f(I_0)$ and $K_{\Sigma} = f(I_0)$ were derived from test results (Fig.2).

The calculated restoring strength will be minimal for examined conditions of its restoration process.

Starting from current above 100 A we observe the influence of electrodynamic forces. The arc quickly reaches upper «ends» of lever contacts and will not be limited in its motion. The arc cooling

DOI: 10.18454/PMI.2017.2.235

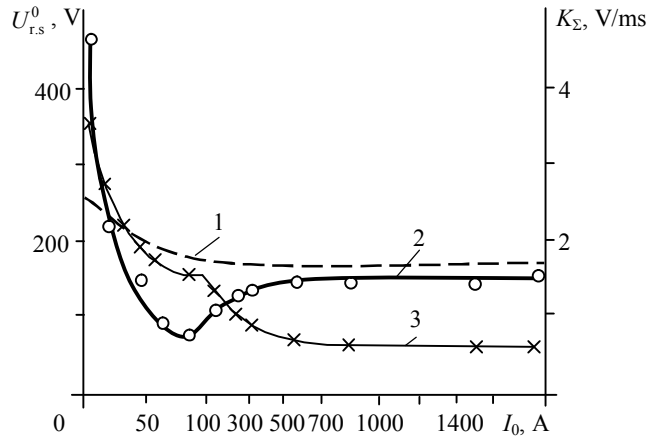


Fig.2. Dependency of initial restoring strength and strength growth speed from cut off current (free arc, copper contacts)

1 – cathodes voltage; 2 – $K_\Sigma = f(I_0)$; 3 – $U^0_{r.s} = f(I_0)$

conditions will improve because it is more mobile and cause some arc root displacement. This improves restoration conditions and leads to its growth. Indeed, starting from the mentioned current values, the curve $K_\Sigma = f(I_0)$ tends to increase, and the curve $U^0_{r.s} = f(I_0)$ decreases less abruptly. The validity of these statements is supported with the fact that minimum of curve $K_\Sigma = f(I_0)$ matches maximum of common dependency of free arc strike from current. The restoring strength should be influenced by plasma flows, which can carry energy from zones near electrodes. The conducted tests considered this influence as integrals. However, it would be practical to carry out special tests to research influence of direction, speed and intensity of plasma flows on restoring strength.

The important test result is that electric strength after current reaches zero $U^0_{r.s}$ is significantly below values of so-called near cathode strength [7].

The difference of results of «initial» restoring strength is explained by different degree of thermoelectronic emission of heated electrodes after zero current under different conditions of tests. If we consider the continuous curve of restoring strength, then we can expect presence of three zones.

The first zone should be right after the point when current passes zero. Its parameters obviously should be determined by arc root cooling processes up to the temperature when its thermoemission stops.

The second zone should correspond to cooling stage of near cathode area and the whole arc column up to the temperature below 3000 K, when thermal ionization of air stops and the restoring strength is no longer influenced by ionized gas particles.

In the third zone, there will be a final restoration of gas dielectric properties; the restoring strength will be determined by gas temperature through its density changes (3000 K > T > $T_{environment}$).

If we agree to this distribution of restoring strength curve, then we can state that measured values of $u_{r.s}$ are mainly within the second zone and sometimes in the first, at its end.

The described test results of researching the restoring strength are relevant for the time periods right after the point when current passes zero for the first time. The following research are of no interest, since rational arc blowout unit should provide arc blowout during the first point of current passing zero level. That is why the first pass dependencies are of key importance.

Test results analysis. The moment of unit contacts break relative to sinusoidal current wave influences the strength restoration process time and its value. Based on tests statistical data we can conclude that at currents of several hundreds of amperes the most unfavorable moment is the contact breakage point, close to the middle of half-period, when arc blowout conditions are the most difficult one, and number of repeated arc strike is the highest [8].

This could be explained by the fact that when contacts break at the end of current half-period and arc and arc root current reaches zero point, contacts have small amount of energy. This improves restoring conditions of electric strength due to relevantly fast cooling of the corresponding zone of gas charge channel after the current reaches zero. When contacts break at the beginning of current half-period there is stable arc stretching due to electrodynamic forces

DOI: 10.18454/PMI.2017.2.235

and separation of unit contacts: arc goes out of narrow zone between contacts and its roots can freely move along them. When conditions of electric strength restoration are favorable, after zero point it grows fast and number of repeated strikes reduces.

If unit contacts are separated in the middle of half-period, then at the end of half-period the arc has no time to go out of narrow zone between contacts and at the same time has a lot of energy. After zero point, there are no favorable conditions for its fast diffusion, that is why the restoring strength is not high enough and number of repeated arc strike is higher than in the other two cases described above [4].

If we look at absolute values of restoring strength at significant cut off currents, we can note that they are not high, at least, not enough to outstay the restoring voltage of hundreds or even thousands of volts, which are possible in low-voltage circuits. Here comes the question: what factors under these conditions provide arc blowout in centiseconds?

Conclusions

1. The stretched electric arc produced at unit contacts gains active resistance, which could be a sequence higher than resistance of cut off circuit.
2. This fact leads to significant reduction of voltage value when current reaches zero point.
3. As a result the restoring voltage reduces abruptly and relevantly low restoring gap strength will be unable to outstay it without breakage.
4. The growing arc resistance greatly reduces circuit current at the following half-periods of arc strike.

REFERENCES

1. Apollonskii S.M., Kuklev Yu.V. Physical processes in electric units. Vol. 1. Teplovye i elektromekhanicheskie protsessy v elektricheskikh apparatakh. Saarbrucken (Germany): Palmarium Academic Publishing, 2012, p.678.
2. Apollonskii S.M., Kuklev Yu.V. Physical processes in electric units. Vol. 2. Dugogasitel'nye ustroistva i problemy sovmestimosti elektricheskikh apparatov. Saarbrucken (Germany): Palmarium Academic Publishing. 2012, p. 476.
3. Apollonskii S.M., Kuklev Yu.V. Low-voltage electric machines. *Zapiski Gornogo instituta*. 2016. Vol. 218, p. 251-260 (in Russian).
4. Taev I.S. Research of electric strength restoration patterns in arc blowout units of DC current control: Avtoref. … d-ra tekhn. nauk. MEI. Moscow, 1967, p. 40 (in Russian).
5. Taev I.S. Electric machines and arc blowout units of low voltage. Moscow: Energiya, 1973, p. 423 (in Russian).
6. Akimov E.G., Burman A.P., Degtyarev V.G. et al. Electric and electronic machines. Pod red. Yu.K.Rozanova. Moscow: Informelektro, 2001, p. 417 (in Russian).
7. Esser W., Systemschutze D. Die neu Schutz-generation. Krockner-Moeller-Post. 1985. Vol. 48. N 98, p. 42-47.
8. Dan A.M. Low-Power Harmonic Impedance Meter. International Conference on Harmonics in Power Systems, 16 October 1984, p.189-193.

***Auhtors*: Stanislav M. Apollonsky**, *Doctor of Engineering Sciences*, *Professor*, *smapollon@yahoo.com* (*Company Ltd «Electromekhanotronika»*, *Saint-Petersburg, Russia*), **Yurii V. Kuklev**, *Candidate of Engineering Sciences, Associate Professor*, *smapollon@yahoo.com* (*Peter the Great Saint-Petersburg Polytechnic University. Institute of Energy and Transport Systems*, *Saint-Petersburg*, *Russia*).
The paper was accepted for publication on 11 April, 2016