INFLUENCES OF AXIAL MAGNETIC FIELDS AND DIFFERENT CONTACT MATERIALS IN VACUUM INTERRUPTERS ON THE CHOPPING BEHAVIOUR OF SWITCHING ARCS

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Abstract

In state of the art vacuum interrupters the current chopping level is in the range of 0.4 … 1.5 A for WCAg40-wt% (weight percent) contact material and 3 … 6 A for CuCr25-wt% in case of interruption up to rated current. This event occurs abruptly, resulting in a high current gradient within nanosecond time scale. At inductive loads, these impulses can cause high overvoltages during interruption operations, which can lead to irreversible damages on the primary equipment. The arc's chopping behaviour can be influenced by different methods: One of these is to form the arc's plasma inside the vacuum chamber by applying a constant external axial magnetic field via the contact gap. The result is a diffuse arc, which forms a homogenous plasma evenly distributed over the entire contact surface. Diffuse arcs tend to burn more stable close to the current zero crossing. This minimizes high current gradients. Additionally, innovative alloys of contact materials can be used to optimize the chopping current behaviour under axial magnetic fields. The main focus of this paper is to investigate the influence of axial magnetic fields on different common contact material compositions for interrupters. In contrast to synthetic test circuits used in other publications with high feeding voltages a simple resistive load circuit is introduced in this contribution. Measurements show that low magnetic flux densities are able to reduce chopping currents by 20 to 30%. This improvement strongly depends on the used electrode alloys and interrupter geometries: In some configurations also an undesirable increase of chopping currents can be observed if an external magnetic field is applied.

1. Introduction

Vacuum interrupters in the medium voltage range for switching of inductive loads are widely used because of their high dielectric strength at small contact gap distances and the increasing importance of environmental aspects [1]. Beside load switches there are circuit breakers which are designed to get an optimum on the breaking capability and therefore focus mainly on robust interruptions. Figure 1 shows a cross section of a standard vacuum interrupter. It consists of the isolating ceramic housing, a movable and a fixed switching contact. The vapour shield is explained in detail in chapter 2.

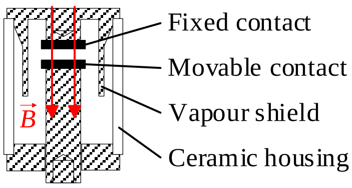

Figure 1: Cross section of a vacuum interrupter with a vapour shield on fixed contact side

In general, the opening sequence of the vacuum interrupter does not occur at the current's natural zero crossing. During opening, the last thin connection of the uneven electrode surfaces results in an exploding micro tip which creates an arc current. At the end of the arcing phase the arc gets instable due to the widening gap in the interrupter and finally chops to zero with a high current gradient d*i*/d*t*. Figure 2 shows an example of a current curve to illustrate the actual current chopping vs. ideal zero chopping. Chopping results in transient overvoltages at inductive loads with risks of subsequent damages of the equipment.

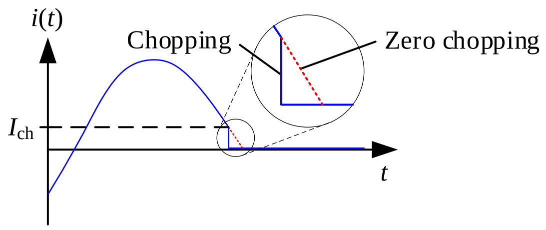

Figure 2: Exemplary current curve with real chopping and desired ideal zero chopping

Low inductive currents with resonance phenomena at several 100 Hz up to 10 kHz are often excited at chopping levels in the range of 0.4 … 1.5 A for the applied WCAg40-wt% contact material and 3 … 6 A for CuCr25-wt% [2].

Several approaches are known and in usage to limit or reduce the impacts of this transient overvoltage at load switches. On the one hand, a reduction can be achieved by close to synchronous switching at zero crossing. On the other hand, protective circuits like surge arrestors limit occurring overvoltages to avoid possible damages at the load. However, protective circuits only reduce the consequences of current chopping but not its causes.

In order to minimize current chopping directly, this paper determines methods for the reduction of chopping currents at load switches and a simplified resistive load circuit has been developed accordingly. Two parameters are being investigated: The influence and comparison of different contact materials and the effect of an externally applied axial magnetic field. The magnetic field is generated by a Helmholtz coil. It is supposed to cause a parabolic course of the current chopping, as has been shown e.g. in [3]. The parabolic course has a direct influence on the arcing and chopping behaviour near current zero crossing at the interruption opening sequence. Additionally, the influence of the vapour shield on fixed-contact or floating potential is considered.

2. Methodology

To investigate the current chopping behaviour during opening operations an experimental test setup is used. The mechanical contact separation with the arcing phase is performed in the positive maximum of the current before its zero crossing. This is realized by a microcontroller with synchronization on the load current. Figure 3 shows the principle structure of the applied test-interrupter. For all tests the middle vacuum interrupter of a three-phase switching device is used, which is equipped with the Helmholtz coil. The fixed switching contact is on top. The moving contact is connected with the actuator.

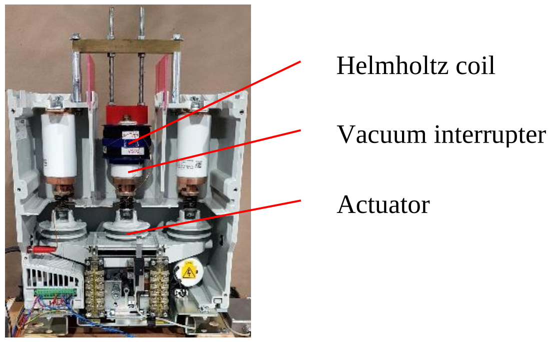

Figure 3: Three-phase switching device. Middle vacuum interrupter with attached Helmholtz coil for adjustable axial magnetic field

A Helmholtz coil placed around the chamber generates a homogeneous axial magnetic field across the contact gap. Because the flux density B cannot be measured directly, it is calculated using the measured coil current and the given geometry [4] of the applied Helmholtz coil by equation:

$$B = \frac{8 \cdot \mu_0 \cdot N \cdot I}{\sqrt{125} \cdot r} \tag{1}$$

Where N is the number of windings per coil and r the average coil radius. All parameters for the interruption experiments are listed in table 1.

Table 1: Test parameters

Frequency	f = 50 Hz
Load impedance	$R \approx 1\ \Omega$
Load current (rms)	I = 45 A
Magnetic field	B = 0 … 140 mT

Figure 4 shows the equivalent circuit of the entire setup which is designed for lower feeding voltages than in [2] and [5]. It includes the voltage source (transformer) at the input of the interrupter and the resistive load to adjust the current which has to be interrupted.

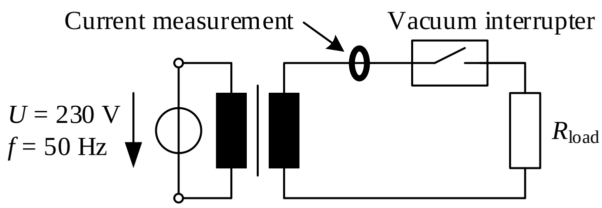

Figure 4: Equivalent circuit of the test setup including voltage supply, load, vacuum interrupter from Figure 1 and sensor for current measurement

The used contact materials in the vacuum interrupter are tungsten carbide silver (WCAg40-

wt%) and copper chromium with variation of the chromium content (CuCr25-wt%; CuCr35-wt%). Thereby WCAg is normally used in load switches and CuCr in circuit breakers. Besides the contact material, the constructional design aspect of the vacuum interrupter is considered in detail. A main component of the vacuum interrupter is the vapour shield (see figure 1). During an arcing process this avoids of an accumulation of vapour metal on the inner ceramic side of the vacuum interrupter insulation housing [6]. There are two different types of shield designs: The shielding is either attached directly on the fixed contact side mechanically and thus on fixed contact potential as shown in figure 1. Or the shielding is fixed at the ceramic cylinder between the fixed and movable contact and thus on floating potential which is not explicit shown in figure 1. Table 2 provides an overview of the investigated configurations.

Table 2: Industrial manufactured vacuum interrupter (VI)

VI-type	Contact material	Shield
VI 1	CuCr35-wt%	On fixed potential
VI 2	CuCr25-wt%	On fixed potential
VI 3	WCAg40-wt%	On fixed potential
VI 4	WCAg40-wt%	Floating

Different magnetic flux densities are investigated:

- Start at 0 T up to 100 mT in 10 mT steps
- From 100 mT up to 140 mT in 20 mT steps

For statistical evaluation 50 opening operations are considered at each flux density. Figures 5 to 8 illustrate the results using mean value and standard deviation for each determined flux density.

3. Measurement Results

Investigations with the optimized and simplified test setup has shown that the chopping current values are comparable to other works [2], [5]. This can be concluded from the direct comparison of the chopping behaviour without magnetic fields (B = 0 T). If an additional magnetic field is applied to the contact gap, desirable current chopping minima can be seen at VI 1 and VI 2 based on copper chromium (Figure 5/6). The minimum chopping current is in the range of B = 30 … 80 mT. This occurs due to the magnetic property of copper: An increased copper content maintains the plasma jet longer even at lower flux densities and thus reduces the chopping current [7]. In these studies, the current values at higher magnetic flux densities remain at a similar level since the maximum impact of the plasma already is active. Thus, higher flux densities do not provide any additional improvements. However, there is no deterioration as with contacts made of copper bismuth aluminium in [3].

For vacuum interrupters with vapour shielding on fixed-contact potential (VI 3, Figure 7) and on floating potential (VI 4, Figure 8) comparable current chopping values are observed using the same contact material. Due to the contact material WCAg40-wt%, a deterioration of the chopping values can be observed at increasing magnetic flux densities. Figure 7 and Figure 8 illustrate this behaviour. The lowest current chopping values without the influence of a magnetic field are in line with [2] and [5]. In general, the chopping current values at WCAg are significantly lower than the ones for CuCr.

The direct comparison of Figures 7 and 8 illustrates the influence of the vapour shield's potential. For VI 3 (Figure 7) with the vapour shield is being connected to the fixed-contact potential the chopping current values increase with the magnetic flux density up to 30 mT. In the range from > 30 mT to 140 mT chopping currents remain at approx. I_{Ch} = 2 A. In comparison, the VI 4 design (Figure 8), with shielding on floating potential, the current chopping values increase over the entire range of magnetic flux densities up to the highest applied flux density.

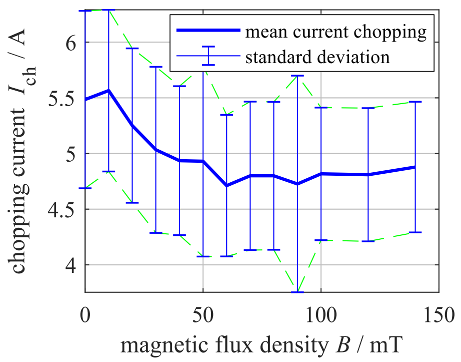

Figure 5: Current chopping measured without and under magnetic flux via the contact gap up to 140 mT. Vacuum interrupter (VI 1) equipped on both contact side with CuCr35-wt%

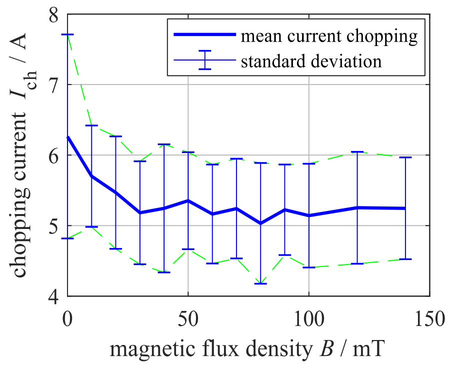

Figure 6: Current chopping measured without and under magnetic flux via the contact gap up to 140 mT. Vacuum interrupter (VI 2) equipped on both contact side with CuCr25-wt%

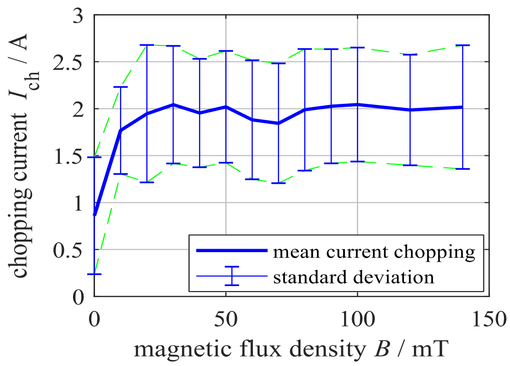

Figure 7: Current chopping measured without and under magnetic flux via the contact gap up to 140 mT. Vacuum interrupter (VI 3) equipped on both contact side with WCAg40-wt%; shielding on potential at fixed contact side

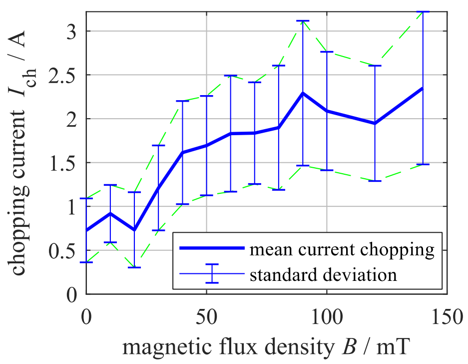

Figure 8: Current chopping measured without and under magnetic flux via the contact gap up to 140 mT. Vacuum interrupter (VI 4) equipped on both contact side with WCAg40-wt%; shielding on floating potential

4. Conclusion

Vacuum interrupters equipped with different contact materials are investigated in an optimized and simplified test setup with regard to their chopping current level behaviour. Arcing behaviour regarding only contact material aspects without the influence of superimposed magnetic fields are in line with those of earlier publications (e.g. [2], [5]).

The focus of this contribution lies on the interruption behaviour if an externally superimposed, axial magnetic variable field is applied. Samples with WCAg40-wt% contact material with both, a metal vapour shielding connected to the fixed-contact potential side and a floating shielding installation show undesirable increased chopping currents under the influence of arising magnetic fields. For configurations using CuCr contacts, the chopping currents can be reduced (meaning improved) by selecting a constant externally applied magnetic field $B > 50$mT. However, this does not always result in the suspected parabolic curve over the magnetic flux density of other contact materials like in [3].

Due to the minima chopping currents discovered in this investigation long-term stresses on inductive components and thus aging effects can be reduced. Also, protective circuits that only attenuate the symptoms generated by the opening process (transient overvoltages) can be partially avoided. For practical applications, it would be price saving to implement the magnetic field application using permanent magnets instead of Helmholtz coils.

Since this contribution determines current jumps with low values (range approx. $I_{ch} = 2 \ldots 5$ A), deviations in the ampere range have a significant effect on the interpretation of the results. The analysis of the data on which the calculation of the standard deviation is based must therefore be examined in further work. The presented results only provide exemplary insights in the influences on currents chopping behaviour.

Based on the findings of this paper with common contact materials, future experimental procedures will consider the impacts of small magnetic flux densities in the range of 0 … 100 mT on new material combinations. Another aspect could be the investigation of the contact geometry and material combinations. Future research will also provide more precise statements regarding chopping parameters. Therefore, a series of measurements over at least ten interrupters of different production cycles should be performed, thus excluding possible influence of manufacturing tolerances.

Also, the aging behaviour of the interrupters will be investigated in further work so that the assumption of a constant magnetic field influence during a life cycle can be confirmed.

5. References

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