Current Interruption in Air for a Medium Voltage Load Break Switch

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***Abstract*—The current interrupting capability of a load break switch (LBS) depends on many design parameters such as contact and nozzle geometry, contact movement and gas flow. For developing more compact gas blow LBSs for air it is necessary to find design recommendations where each parameter is addressed individually. In the present paper a current interruption test switch is built for this purpose. The interruption tests are conducted with a directly powered high voltage circuit. The result shows the minimum gas flow required for current interruption for various basic nozzle geometries and at different contact positions. The study is particular relevant for the 24 kV / 630 A class, and it is shown that 0.3 bar upstream pressure appears to be a threshold value for successful interruption. Some conclusions are also applicable for other medium voltage ratings. A LBS should be designed so that at least one current zero crossing comes outside the nozzle when the switch is still blowing with full strength.**

***Index Terms*—Load break switch, switchgear, medium voltage, puffer breaker, current zero, thermal interruption, air**

I. Introduction

LOAD break switches (LBS) are widely applied in medium voltage (MV) distribution networks. A LBS is less powerful than a circuit breaker and interrupts currents up to approximately one kiloampere [1]. The most common types have a gas blow arrangement (usually called puffer) to quench the arc, but vacuum devices also exist.

LBSs are often an integrated part of a metal enclosed or metal clad switchgear assembly comprising several MV components. The filling gas is air or SF_6, sometimes pressurized for improving the current interruption performance and increasing the dielectric strength, allowing for more compact switchgears.

From an environmental perspective, air filled switchgear are preferred over SF_6 products, but air has poorer dielectrical and current interrupting performance than SF_6. Although the capabilities can be improved by increasing the filling pressure, air insulated switchgear tend to become substantially larger than when using SF_6. Hence, to make air filled switchgear competitive, optimizing the design with regard to size becomes crucial.

Little is published about design of LBSs using air as interrupting medium because SF_6 technology has dominated the marked for metal enclosed switchgear. The current interruption capability depends on many design parameters such as gas flow, contact separation speed, geometry and choice of materials for the nozzle and the contacts.

The present paper reports on an experimental study of current interruption in air. A test switch is built, and nozzle geometry, air flow and contact movement are systematically varied. The test circuit is based on the so-called ”mainly active load test duty” for 24 kV / 630 A class of LBSs, as prescribed by the International Electrotechnical Commission (IEC) [2].

The purpose of the work is to investigate in a quantitative manner how some of the above mentioned parameters influence the interrupting capability. Such knowledge is expected to be valuable for developing competitive and compact air LBSs.

Initially, the test setup and procedure are descried. Then results from 580 interruption tests with five different nozzle geometries are presented, determining the minimum air flow required for successful interruption.

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II. Experimental

A. Test Switch

Fig. 1 shows the test setup and Fig. 2 the contacts and nozzle arrangement in detail. The contacts are made of an arc resistant copper-tungsten alloy, whereas the nozzle is made of polytetrafluorethylene (PTFE). The contact pin is 6 mm in diameter and penetrates 60 mm into the female or tulip part in closed position. Five nozzles with various lengths L and inner diameters D were tested. The parts have a simple, axisymmetric design and are easy to replace.

The test setup uses a spring mechanism to open the contact. After the spring has been charged an electromagnet holds the movable contact in place until the control current in the magnet is interrupted. This way of releasing the pin contact is reliable and precise. Moreover, the contact opening can be synchronized with the voltage waveform making it possible to predetermine the contact gap x (see Fig. 2) when the first current zero (CZ) crossing occurs.

The force provided by the spring, and thereby the contact velocity, can be adjusted by changing the compression of the spring. The spring accelerates the pin contact for the first 60 mm, that is exactly until the pin and tulip separate. From then on the pin moves with almost constant velocity. Arcing wear causes some variation in the friction, yielding some randomness in the contact movement. It is found that the contact position at the first CZ can be preset with an accuracy of within ± 5 mm.

A reservoir of compressed air provides the air blow during interruptions. When the switch is in closed position, the contact pin plugs the air outlet. As the pin leaves the tulip

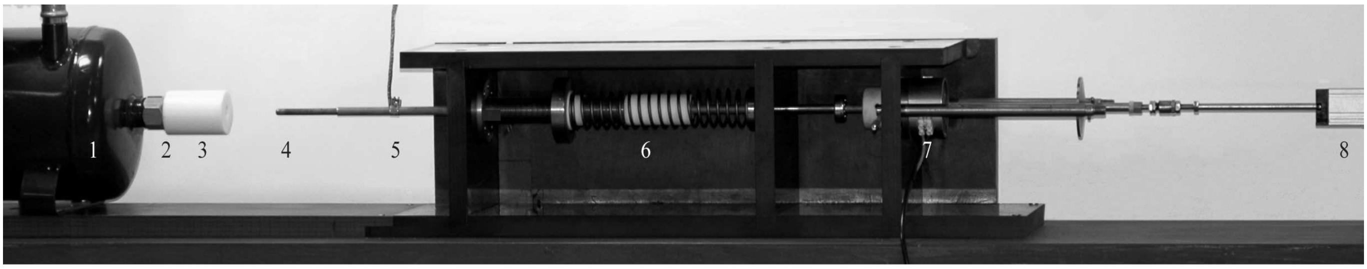

Fig. 1. Test switch. The numbered parts are 1. Compressed air reservoir (connected to the high voltage supply circuit), 2. Tulip contact, 3. Nozzle, 4. Pin contact, 5. Connection to load circuit, 6. Spring drive mechanism, 7. Electromagnet release mechanism, and 8. Position transducer.

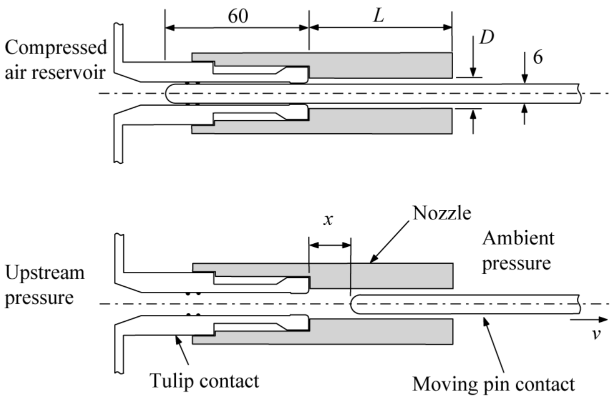

Fig. 2. The axisymmetric contact and nozzle geometries in closed position (upper drawing) and shortly after opening (lower drawing). L and D are the length and inner diameter of the nozzle, respectively. The contact position is x. Dimensions are in millimeters.

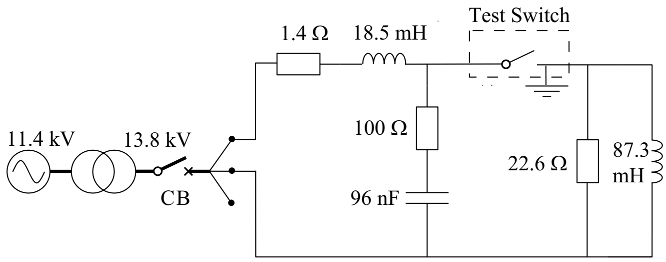

Fig. 3. The high voltage test circuit. The impedances of the system and transformer are incorporated in the component values shown. The circuit breaker (CB) is controlled from the laboratory and connects and disconnects the test circuit from the power source.

contact during opening, compressed air is released through the nozzle and blows on the arc. The volume of the air reservoir is sufficiently large for the pressure drop through the nozzle, usually referred to as upstream pressure, to remain virtually constant during the few power cycles an interruption lasts. By changing the air pressure in the reservoir, different air flow rates are obtained.

This setup allows for current interruption experiments for different nozzle lengths and inner diameters, while varying the contact velocity, upstream pressure, and position of the first CZ independently of each other.

B. High Voltage Circuit

Fig. 3 shows the high voltage circuit used for the interruption tests. The circuit is a single-phase version of the "mainly active load test duty" type test of the LBS standard issued by IEC. The component values are set to give a transient recovery voltage (TRV) that in the first and critical 100 μs is nearly identical to that specified by the standard for the 24 kV / 630 A class. (As shown in a separate paper [3], the initial part of the TRVs for the entire MV range of LBSs can be created with a source voltage of only 13.8 kV.) Hence, the present experiments primarily address the thermal phase of the current interruption process. Dielectric re-strikes are hardly a concern for typical LBS designs.

The circuit is grounded on the load side of the test switch, which is possible since there is no other grounded point on the secondary side of the laboratory transformer. The TRV between the contacts is measured with a capacitive voltage divider and current with a Hall effect current transducer. A second voltage divider with a range only up to 350 V is used to accurately determine when the CZ occurs. A resistive transducer to the far right of the test switch in Fig. 1, measures the position of the moving contact as a function of time. All these measurements are transmitted via optical fibers and fed into an 12 bit resolution transient recorder with a sampling frequency of 5 MHz. The static pressure in the air reservoir is measured with a high precision (accuracy better than 0.01 bar) pressure sensor before each test.

C. Procedure

Initial tests with different upstream pressures using a L = 30 mm long and D = 9 mm wide nozzle indicated that an upstream pressure in the range 0.2 - 0.4 bar was needed for successful interruption. Therefore, the systematic investigation started by using this nozzle size and 0.3 bar upstream pressure. In subsequent test series nozzle lengths of L = 15 mm and L = 60 mm with diameters of D = 9 mm were applied. For L = 30 mm test series with two other diameters, D = 8 mm and D = 10 mm, were also run.

For each upstream pressure 20 interruption tests were performed. The release of the pin contact was synchronized with the current waveform and evenly distributed over the 10 ms long time span of a half cycle. With a contact velocity of around 5 mm/ms, this results in a fairly even distribution of the contact position at the first CZ, in the range 0 - 50 mm.

For each nozzle size the upstream pressure was increased in steps of 0.05 bar, staring from 0.3 bar. This procedure continued until no further improvement of the current interruption capability was observed. After this, the upstream pressure was decreased below 0.3 bar, until all interruption attempts failed.

A failed interruption causes substantial more contact and nozzle wear than a successful one. Therefore, the test series with higher upstream pressure were carried out first, keeping the nozzle and contacts close to original condition longer. The nozzles were not replaced. The surface of the contact was regularly inspected and smoothened with a fine sandpaper.

III. RESULTS

A. Examples of Measurements from Typical Experiments

Fig. 4 shows measured current and TRV waveforms from a 400 μs long time interval around CZ from a typical interruption experiment. IEC specifies that for the 24 kV / 630 A case the first peak of the TRV should have a rise time of 96 μs and an amplitude of 7.6 kV. As can be seen, this requirement is met.

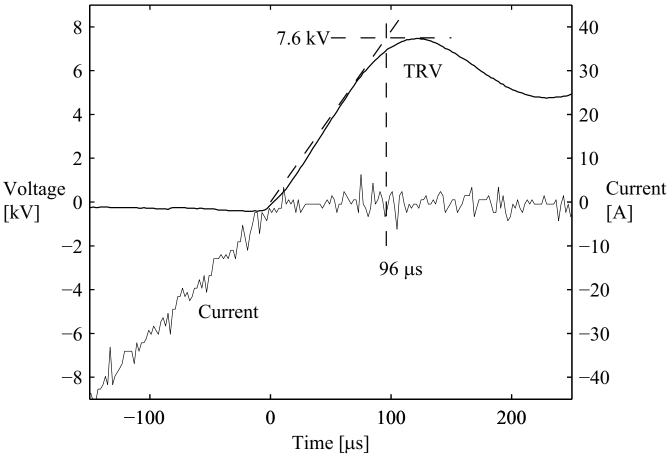

Fig. 4. Typical unfiltered measurements of current and TRV from an interruption experiment. Only a 400 μs time interval near CZ is included. The 7.6 kV amplitude and 96 μs rise time are the parameter values defined by the IEC for the 24 kV / 630 A class.

Figs. 5 and 6 present data recorded from typical successful and failed interruption experiments, respectively. The upper part of the figures shows the voltage across the contacts and the current, whereas the lower part contains the contact travel curve (i.e., the pin contact position as a function of time) and the contact voltage recorded with a different voltage divider, measuring only from -350 V to +350 V. The time axis is adjusted so that t = 0 corresponds to the first CZ after contact separation. The figures show that the pin contact in these cases separates from the tulip contact at about t = -7 ms as an arc voltage starts to build up. At t = 0 when the first CZ occurs and current is interrupted in the case shown in Fig. 5, the contact gap is 27 mm. In the case of the successful interruption, it can be observed that the contact voltage immediately after has a first peak as specified by the standard (shown in Fig. 4).

In Fig. 6 the arc re-ignites both at the first and second CZ, and current continues to flow. The amplitude of the arc voltage is between 100 and 200 V for most of the time after the failed interruptions, somewhat larger in the second half cycle since the arc length increases.

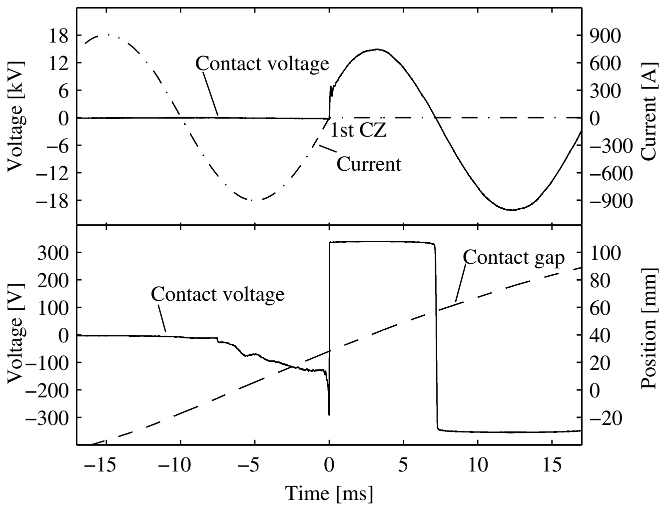

Fig. 5. Contact travel curve and current and voltage waveforms for a typical example of a successful interruption where the arc is quenched and current interrupted at the first CZ after contact separation. The contact voltage measurement in the lower graph is obtained with a voltage divider that has a limited range; it saturates at voltage amplitudes of around 350 V.

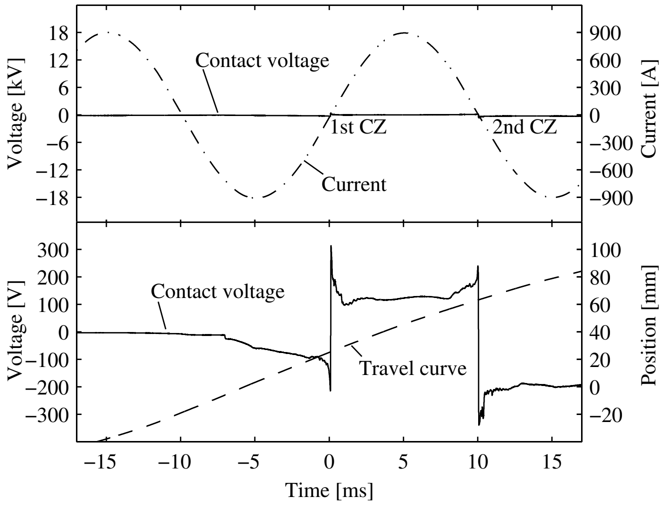

Fig. 6. Contact travel curve and current and voltage waveforms for a typical example of a failed interruption where the arc re-ignites both after the first and second CZ.

B. Interrupting Capability at Different Contact Positions and Upstream Pressures

In Fig. 7 the results of a large number of interruption tests with different nozzle lengths (the parameter L in Fig. 2) are presented, as a function of the contact position (the parameter x in Fig. 2) at CZ for different upstream pressures. Fig. 8 shows similar plots, but with the nozzle inner diameter (the parameter D in Fig. 2) being varied. Note that both figures contain the results for the L = 30 mm and D = 9 mm experiments, so these are for the sake of comparison shown twice.

In both Figs. 7 and 8 a successful interruption is marked with an open symbol in blue, and an interruption failure with a filled red symbol. Circular symbols are for the first CZ and triangular symbols for the second CZ. Each current interruption experiment can thus have three different outcomes:

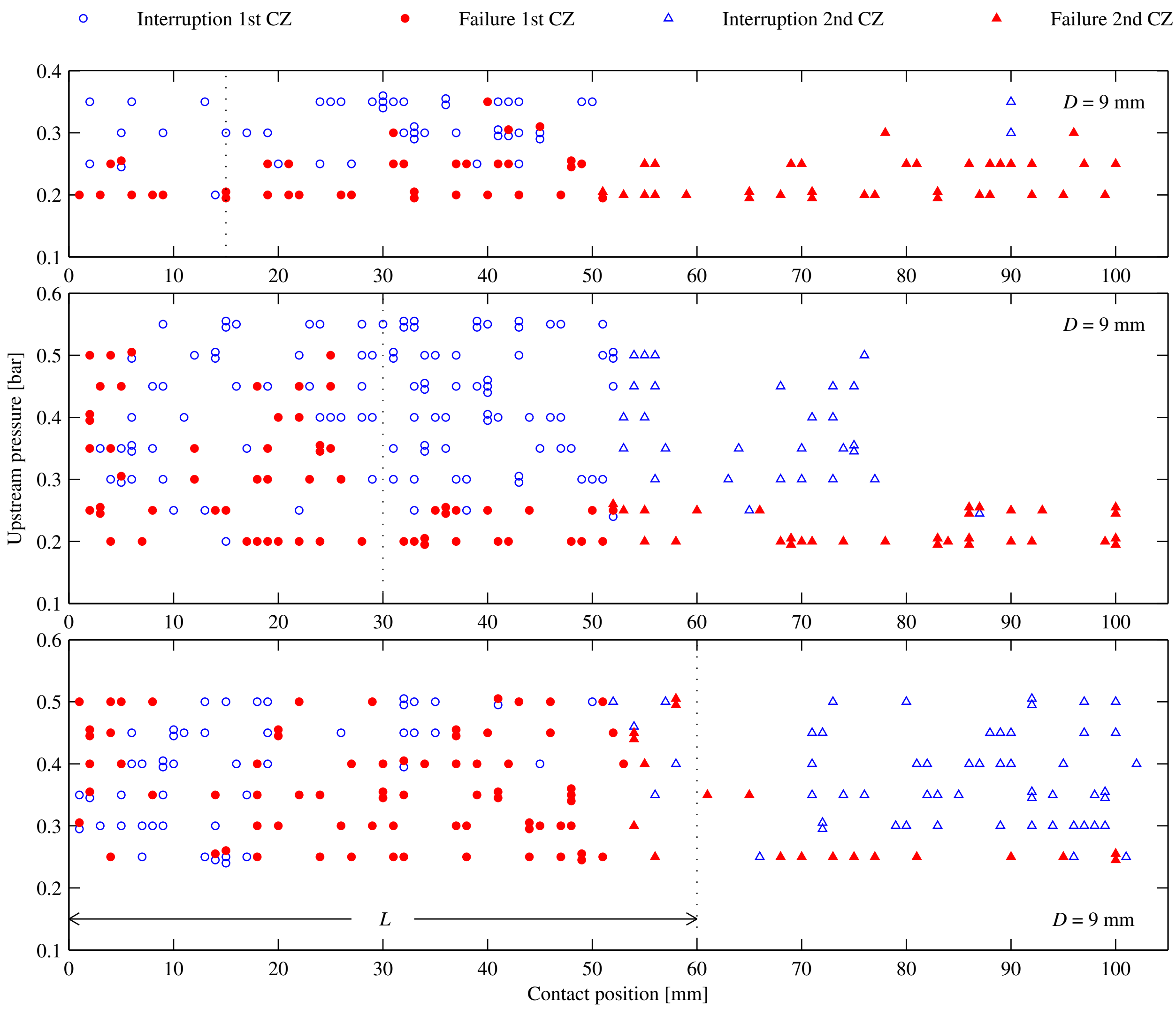

Fig. 7. Results from current interruption experiments with different upstream pressures and for nozzle lengths of 60 mm (lower), 30 mm (middle) and 15 mm (upper), as indicated with the dotted lines. The nozzle inner diameter is in all cases 9 mm. The outcome of every interruption attempt, successful or failed, both at first and second CZ, are included and plotted as a function of the contact position. When two or more experiments happened to occur at the same pressure and contact position, some of the symbols are for reasons of clarity shifted a little in the vertical direction.

- Successful interruption at first CZ. Marked with an open blue circle.
- Failed interruption at first CZ, then successful interruption at second CZ. Marked with a filled red circle and an open blue triangle separated by approximately 50 mm (contact speed is around 5 mm/ms and the CZs are 10 ms apart).
- Failed interruption at both first and second CZ. Marked with a filled red circle and a filled red triangle separated by approximately 50 mm.

Hence, each test series of 20 shots gives 20 circles and as many triangles (filled and unfilled) as there are filled red circles.

It is clear from these experiments that the interruption capability is better outside the nozzle. This is particularly evident when considering the middle and lower parts of Fig. 7. For upstream pressures of 0.3 bar or greater, all the filled red circles signifying failed interruption at first CZ are here located to the left of the dotted line indicating the nozzle length. The same applies for the upper curve in Fig. 8. Above a certain upstream pressure, interruption failures occur almost only when the CZ comes while the contact pin is still inside the nozzle.

For the 60 mm long nozzle some of the second interruption attempts (i.e., at the second CZ after contact separation) take place while the contact pin is still inside the nozzle. Several of these fail, as indicated with the filled red triangles between x = 50 and x = 60 mm in the lower part of Fig. 7. However, for the majority of the tests the second CZ comes when the contact pin is outside the nozzle (i.e., for $x > L$), and these do in nearly all cases result in successful interruption as long as the upstream pressure is above a certain level.

The magnitude of the upstream pressure is obviously crucial to the interrupting capability of this setup, and of far greater importance than the length and inner diameter of the nozzle. For upstream pressures of 0.3 bar and above, the chances for

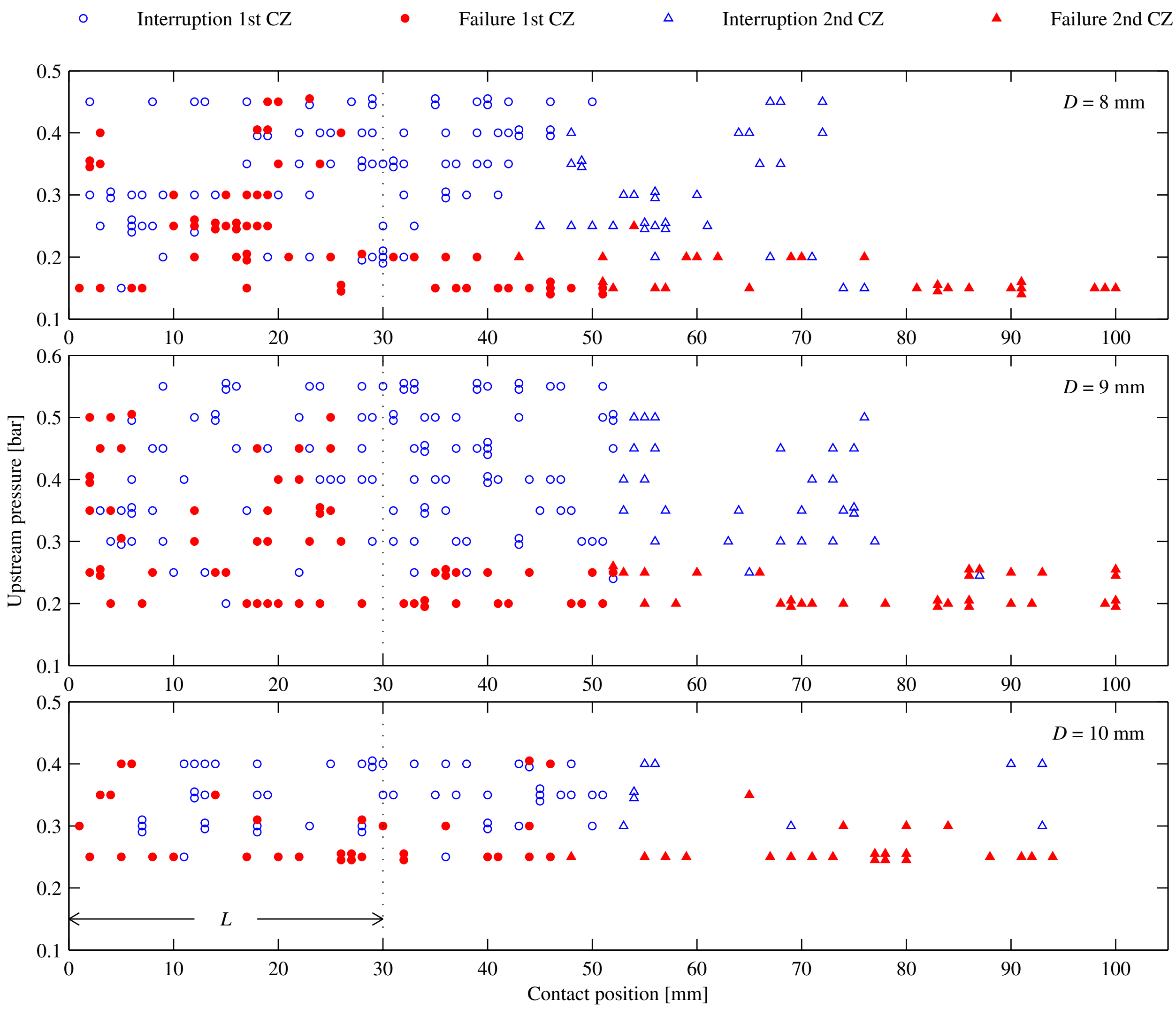

Fig. 8. Results from current interruption experiments with different upstream pressures and for nozzle inner diameters of 10 mm (lower), 9 mm (middle) and 8 mm (upper). The nozzle length is in all cases 9 mm, as indicated with the dotted lines. The outcome of every interruption attempt, successful or failed, both at first and second CZ, are included and plotted as a function of the contact position. When two or more experiments happened to occur at the same pressure and contact position, some of the symbols are for reasons of clarity shifted a little in the vertical direction.

a successful interruption in the first or second CZ are good as long as at least the second CZ comes when the pin contact is outside the nozzle. Otherwise the nozzle length seems to be of minor importance. Reducing the inner diameter of the nozzle from 10 to 8 mm appears to improve the interrupting capability somewhat. These findings are further illustrated in Fig. 9 which shows the percentage of successful interruptions for the 20 tests that were carried out for each nozzle length and diameter combination. An interruption test is here considered successful irrespective of whether the current was interrupted at the first or second CZ.

Again, the interrupting capability obviously depends greatly on the upstream pressure and to a much lesser extent on nozzle length and inner diameter, even though a narrower nozzle brings some benefits at low upstream pressures. An excessive nozzle length is however not a good solution as even a high upstream pressure some times gives failed interruptions if both first and second CZ occur while the contact pin is inside the nozzle. This comes out in Fig. 9 as success rates for the L = 60 mm tests of only 90 - 95 %, even at high pressures.

Dielectric re-ignitions were never observed in this investigation. Unsuccessful interruptions were always characterized by current starting flowing again within a few microseconds after CZ, signifying that a thermal re-ignition occurred. Successful interruptions were observed even for contact gaps as small as 2 mm. With the first peak amplitude of the TRV of 7.6 kV (see Fig. 4) this means that the average electric field across the gap reached as high value as approximately 3.8 kV/mm, without causing a re-ignition of the arc.

IV. Discussion

The contact velocity during opening of a LBS is related to the type test requirements. These include withstanding a lightning impulse across open contacts. For the 24 kV level

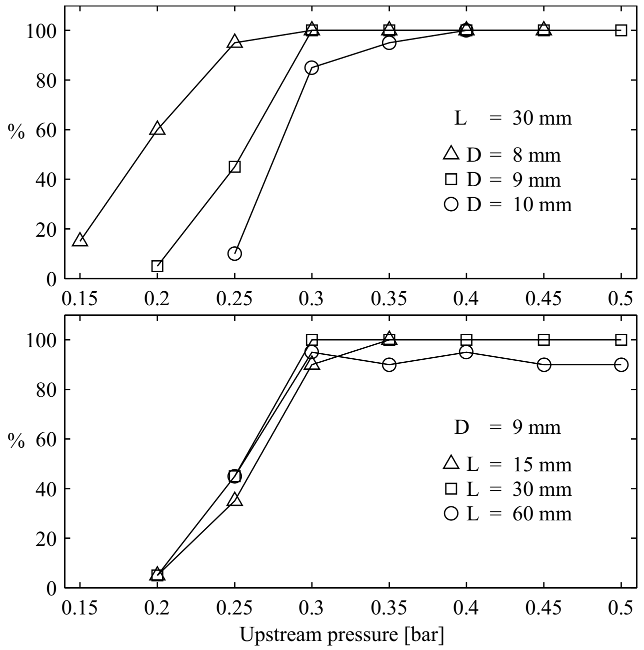

Fig. 9. Percentage of successful interruptions as a function of the upstream pressure for all test series.

this typically implies that the gap across fully opened contacts must be in the range 100 - 150 mm for air insulated devices installed in metal enclosed switchgear. Moreover, a typical LBS is designed to interrupt the current in the first or second (or sometimes third) CZ, and at the latest when the contacts are approaching the fully open position. This infers a contact velocity during opening of typically 4 - 5 mm/ms. Hence, the contact travel characteristics of the test setup are comparable to that of real devices.

Concerning nozzle and contact geometries, the test switch is of a very simple, axisymmetric design, but still having the most important features of typical commercial devices, including using a PTFE nozzle and copper-tungsten contacts. The arrangement for generating the air flow, on the other hand, is completely different from commercially viable solutions. Often a piston and cylinder system is applied. However, for investigating the effect of a different air flow the used setup appears to be well suited.

As shown from the experiments the interruption capability is unpredictable if the pin contact is still inside the nozzle. The reason for this is probably that the air stream then is partly blocked by the pin contact. But once the pin moves out from the nozzle the flow rate will increase. However, it is still puzzling that the probability for interruption is not much increased when the upstream pressure is increased from 0.3 and to 0.5 bar, if only comparing when the pin in still inside the nozzle.

For upstream pressures lower than 0.3 bar, the smaller nozzle diameter performs better. The air stream is for all nozzle dimensions in this study limited by the 6 mm wide tulip contact. Without an arc, the flow rate and maximum flow speed will mainly be determined by the tulip dimension, since this is the most narrow part of this setup. For that case a 6 mm wide nozzle will then best keep up the speed of the air, while the larger the nozzle becomes, the slower the air will flow through the nozzle. However, when an electric arc is present, the nozzle part will to larger extent limit the air flow, and the discussion about air speed and flow rate through the system becomes more complex. A too wide nozzle will lead to lower air speed and creating too much space for the air to pass around the arc, not cooling it efficiently. On the other hand, a too narrow nozzle will not necessarily perform well either, since the arc then might clog the air flow. Therefore, the nozzle diameter needs to be carefully selected.

Changing the tulip diameter will have a large effect on the air flow through the nozzle. Both the speed of the air and the amount of air passing the nozzle per time unit are expected to be important for the interruption capability. Therefore, a continuation from the present study would be to investigate the influence of the contact diameter, and in addition with different nozzle shapes.

The TRV generated by the test circuit complies well with the type test requirements for the first hundred microseconds, but deviates considerably later on. The reason is essentially that a 13.8 kV and not a 24 kV voltage source is used. This is however not expected to influence the results. If an interruption fails, it does so in the thermal recovery part, long before the first peak of the TRV. A 24 kV source gives a maximum recovery voltage of around 33 kV, not 19 kV as in the present 13.8 kV circuit, but this maximum occurs several milliseconds after the interruption. For the second and critical CZ, the contact gap has then reached at least 50 mm, giving an average electric field of no more than 0.7 kV/mm, and consequently, no risk of a dielectric re-ignition.

In conclusion, the results obtained with the simple test switch and the applied high voltage circuit are assumed to provide clues about critical design parameters for a MV LBS operating in air. In a commercial LBS the puffer arrangement needs to be carefully designed to provide a sufficient upstream pressure. Knowing the magnitude of the minimum upstream pressure may simplify the development of an LBS, and in particular reduce the need for electrical tests during the design phase.

V. Conclusions

The main findings from this parameter study of interruption of 630 A at 24 kV in atmospheric air using a simple test switch are:

- The main challenge is to avoid thermal re-ignition immediately after CZ. Dielectric re-ignition is less of a concern.
- For the investigated contact and nozzle geometries an upstream air pressure of at least 0.3 bar is crucial for obtaining a good interrupting capability.
- The interruption performance is not very sensitive to the length and inner diameter of the nozzle for this type of design.
- The length of the nozzle and contact pin velocity should be so that the second CZ after contact separation always comes when the contact pin is outside the nozzle.

References

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