 

# CONTACT AND NOZZLE WEAR FROM 100 INTERRUPTIONS FOR A PUFFER-TYPE AIR LOAD BREAK SWITCH

N. Støa-Aanensen*, E. Jonsson, M. Runde

*SINTEF Energy Research, 7465, Trondheim, Norway*

* nina.stoa-aanensen@sintef.no

**Abstract.** One type test requirement for medium voltage load break switches is to interrupt 100 consecutive "mainly active loads". A puffer-type switch with axial-blown arc has been tested according to the 630 A/24 kV ratings. The nozzle and contact wear were measured regularly to investigate design requirements and the impact from nozzle wear on gas flow. The contact wear is only moderate, while the nozzle wear causes a decrease in pressure build-up, which in turn may influence the interruption performance.

**Keywords:** load break switch, switchgear, medium voltage, electric arc, puffer switch, nozzle wear.

## 1. Introduction

In the recent years, substational efforts have been made to develop $SF_6$-free switchgear to reduce the use of greenhouse gases in the electrical industry [1]–[4]. One of the most challenging aspects when designing and producing a compact $SF_6$-free load break switch (LBS) is to make it cost-efficient. Since both currents and voltage stresses are moderate compared to fault current interruptions and higher voltage ratings, the difficulty of making a medium voltage (MV) LBS is not necessarily the current interruption itself, but to do it at fairly low gas pressure, in a compact and small device, and to a low manufacturing cost.

The various parts of a switch are subjected to repeated stresses during their life-time, both mechanical and from the current and arc heating. Consequently, they need to be made of durable and often expensive materials. Often, cost reduction comes with a lower performance, calling for trade-offs. Some examples are reducing the use of silver plating versus the increased heat losses, or decreasing the sizes of the expensive arcing contacts versus wear of these by the electric arc.

This paper reports a study on the arcing contact and nozzle wear from 100 consecutive interruption operations with a single-phase version of the 24 kV/630 A "mainly active load" test duty as described by IEC [5]. A puffer-type setup with axial cooling flow and air as the interrupting medium is used.

There are several issues related to the wear of a puffer switch during testing. The arcing contacts are expensive and should not be made larger than necessary. Thus, it is important to observe their mass losses and any change in diameter. Moreover, the nozzle wear could change the outlet area from the puffer volume, and consequently the cooling air flow itself. These topics are covered and discussed in this paper.

## 2. Setup and procedures

The experimental work is carried out with a test circuit that is directly powered by the MV grid. The circuit setup is described in detail elsewhere [6]–[7]. The current to be interrupted is approximately 630 A. The transient recovery voltage (TRV) can be described by a rate of rise of recovery voltage (RRRV) of approximately 80 V/$\mu$s and a first voltage peak of 7.5 kV. This corresponds to the type tests for a 24 kV LBS. Air is used as the interrupting gas, and the starting pressure is atmospheric.

The puffer test switch is shown in Figure 1. A stationary contact set including main contact and the pin arcing contact is seen to the right in the figure. The puffer volume is created with a cylinder, a stationary back wall and a moving puffer disc. The moving main and arcing ring contacts are attached to the puffer disc. Before testing, the puffer disc is positioned to the right end of the puffer cylinder, and the main contact is closed. During a current interruption, the puffer disc and moving contacts are pulled away from the stationary contacts, the puffer volume decreases and the pressure rises. The compressed air vents out from the puffer volume through ten holes in the middle of the puffer disc and further out through the arcing ring contact after contact separation and to the arcing zone. A cylindrical polytetrafluoroethylene (PTFE) nozzle is attached on the outside of the arcing ring contact to guide the air flow onto the arc, and to prevent flashover from the arcing contact to the main contact set. The total contact movement is around 90 mm, where 24 mm is before arcing contact separation.

The diameter of the ring and pin arcing contacts is 7 mm. The nozzle has an inner diameter of 7.3 mm at the start of the experiment, and the nozzle channel is 12 mm long. A pre-compressed spring is released by a trigger signal to start the movement of the ring contact and the compression of the puffer volume. To vary how far the contact has moved before current zero (CZ),

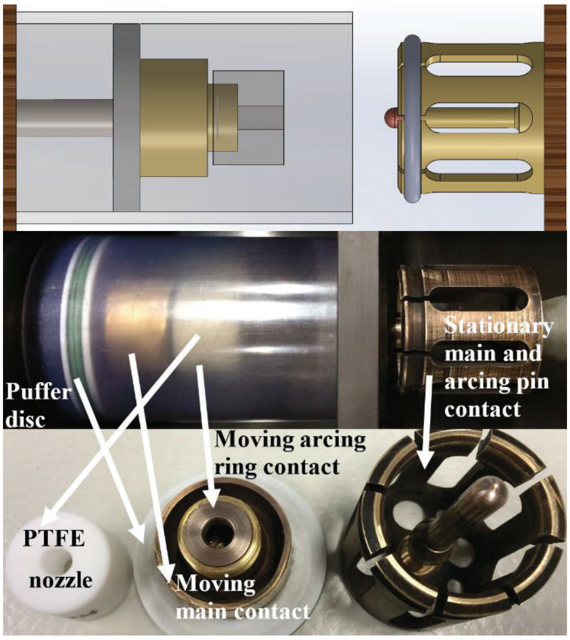


*Figure 1. The puffer test switch and its main components. Arcing contacts are made of copper tungsten, while the main contacts are of brass.*

the triggering set point is changed throughout the test series. The spring or the amount of pre-compression is not changed, but friction from the puffer disc or between the arcing contacts may slightly alter the contact velocity from test to test. The pressure build-up itself also affects the movement; the higher the over-pressure in the puffer volume, the larger force must be applied to keep the movement at a constant velocity.

In order to keep track of the nozzle and contact wear during the 100 interruptions, the test switch is disassembled after every 10 tests. The nozzle and contact diameters and masses are measured. Moreover, the cold flow (no arc) pressure build-up as a function of contact movement is recorded to see to what extent the wear changes the pressure profiles and behaviour of the puffer device.

## 3. Experimental results and discussion

Figure 2 shows typical measurements from a current interruption test. The first CZ was a failed interruption (occurred with the pin contact still inside the nozzle), while the second attempt was successful. All interruption tests were successful at first attempt outside the nozzle. A few even interrupted with the pin contact still inside the nozzle channel.

The current was in the range 336 A to 349 A. The contact velocity around current interruption was 2–3 m/s, depending on the pressure build-up and the contact gap. An LBS in normal operation cannot control at what contact position the CZ crossings occur, and the switch should be able to interrupt the

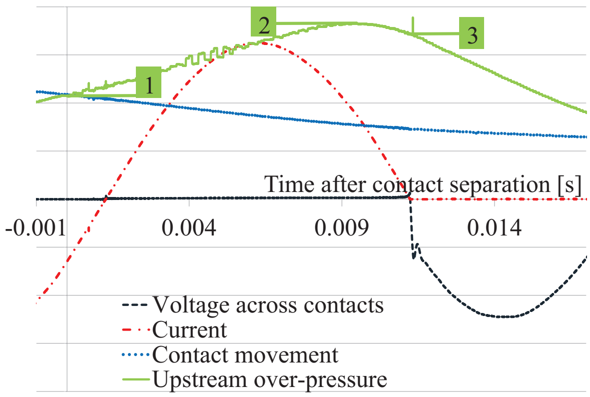


*Figure 2. Current interruption test with measurements of contact position, voltage and current across the contact gap, and the over-pressure in the puffer volume. Pressure at contact separation (1), the peak pressure (2), and the pressure at interruption (3).*

current within the first two CZs, independent of when the contacts separate. In this test series, the triggering time was varied, and the interruptions occurred at contact gaps from 1 to 35 mm.

### 3.1. Nozzle and contact wear

The arcing contacts had no notable change in their diameters during the 100 tests. Their weight reduction was 0.04–0.05 g, or less than 0.6% of the total mass of the pin contact tip and below 0.3% of the ring contact. The 100 consecutive interruptions of the "mainly active load" test duty is one of the toughest requirements for the arcing contacts, and often determines the minimum dimensions of the expensive copper-tungsten contacts. In this test, the diameter was 7 mm, which does not seem to be a limiting factor when designing a durable switch for load currents of 630 A. The main contacts must be dimensioned based on the rated current amplitude and the maximum permissible temperature during normal operation.

The measured inner diameter of the nozzle is listed in Table 1. Both side-to-side and top-to-bottom were measured, that is, at a 90° angle. Although there is some asymmetry, the nozzle inner diameter increased by approximately 1 mm, or 14%, during 100 interruption tests. The total mass loss was 0.5 g, or 2.2%.

The nozzle wear can affect the current interruption capability in several ways. First, a larger nozzle-to-contact diameter ratio requires an increased over-pressure for successful interruption [8]. Second, an increase in the nozzle diameter changes the outlet area when the pin contact is still inside the nozzle, and could thus change the pressure build-up in the puffer volume.

### 3.2. Pressure build-up

Figure 3 shows the cold flow measurements of pressure and contact position carried out before and during

| Test no. | Side-to-side [mm] | Top-to-bottom [mm] |
|---|---|---|
| 0 | 7.31 | 7.31 |
| 10 | 7.39 | 7.40 |
| 20 | 7.58 | 7.60 |
| 30 | 7.65 | 7.66 |
| 40 | 7.76 | 7.69 |
| 50 | 7.87 | 7.86 |
| 60 | 7.96 | 7.96 |
| 70 | 8.07 | 8.08 |
| 80 | 8.15 | 8.13 |
| 90 | 8.26 | 8.25 |
| 100 | 8.32 | 8.37 |
| Difference | 1.01 | 1.06 |

*Table 1. Measured nozzle inner diameters.*

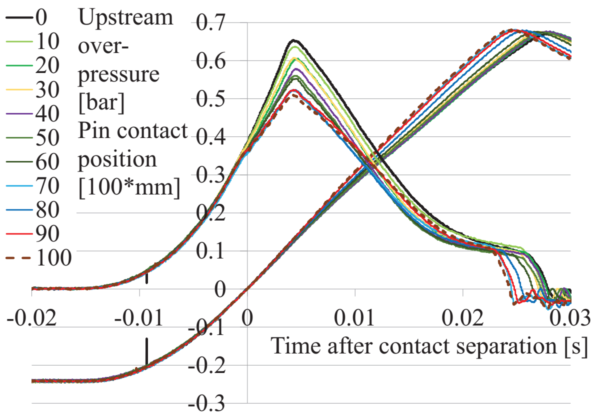


*Figure 3. Cold-flow measurements of puffer volume over-pressure and contact movement from before start of test series (0) to after 100 tests (100).*

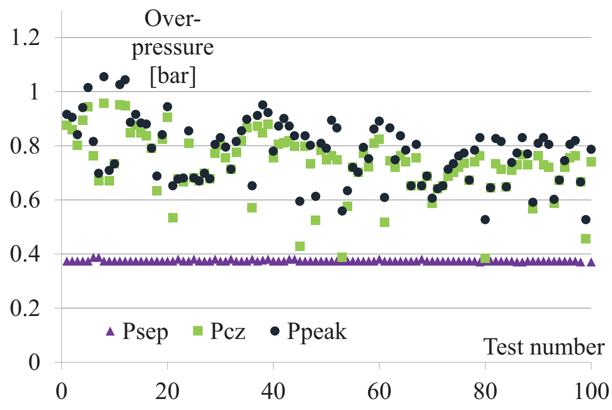


*Figure 4. Over-pressure in puffer volume at contact separation (Psep), at CZ and current interruption (Pcz), and the maximum over-pressure (Ppeak).*

the test series. The black lines represent the measurements before the interruption tests (labelled "0"), the red lines represent the measurements after 90 tests, etc. There are two lines per cold flow test, namely the upstream over-pressure (starts at 0 bar) and the pin contact position relative to contact separation (starts at -24 mm).

The movement and pressure build-up before the contacts separate do not change much during the 100 tests. In this period, the pin contact is blocking the only outlet, and the pressure rise is consistent with adiabatic compression of the puffer volume. As long as the pin and ring contact do not change size during the test series, this pressure build-up is expected to be the same each time.

The variations start after contact separation. The newer (and narrower) the nozzle, the higher upstream over-pressure is achieved in the puffer volume. The maximum over-pressure is around 0.65 bar before the test series, and about 0.5 bar after 100 interruptions. It is important that also the 100th interruption test builds up high enough over-pressure to interrupt.

The trend is similar for the pressure measurements with arcing. Figure 4 shows the pressures at contact separation, current interruption and the peak pressure for all tests. Whereas the pressure at contact separation is constant, and similar to the cold-flow cases, the peak pressure and pressure at current interruption decrease during the course of the tests. Furthermore, the pressure is in general higher than in the cold flow cases, due to clogging of the outlets by the arc. The maximum over-pressure in the cold flow cases was not above 0.65 bar. Now, the over-pressure exceeds 1 bar, depending on the contact position at current interruption.

With the switch design used in this work, 100 "mainly active load" test duties are sufficitent to significantly alter the PTFE nozzle inner diameter and consequently the cooling gas flow. Obviously, a switch must be designed by taking nozzle wear and its influence on the gas flow into consideration.

### 3.3. Arcing energy

As the triggering time and the contact gap were varied throughout the test series, so was the arcing energy per test. The arcing energy for each test, together with the cumulative arcing energy are shown in Figure 5. The arcing energy per test varied from as low as 53 J (a test where the current was interrupted right after contact separation) and up to 835 J. In total, the arcing energy of the test series was 31.7 kJ. The total nozzle mass loss was 0.5 g.

In [9], thermogravimetric analyses (TGA) were carried out to measure the energy needed to evaporate PTFE by slow heating of the material. In addition, arcing experiments were carried out in the vicinity of PTFE plates, and the PTFE mass losses were compared to the energy dissipated in the arc. The energy required to evaporate or "remove" 1 g PTFE was found to be 1485 kJ/g and 87.1 kJ/g, respectively, in these two cases.

If it is assumed that all the energy dissipated by the arc during the 100 interruption tests is absorbed

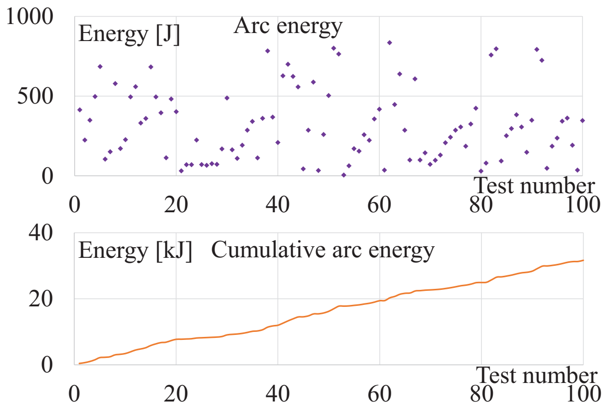


*Figure 5. The arcing energy of each interruption test, and the cumulative arc energy for the entire test series.*

by the PTFE nozzle, it corresponds to 63.4 kJ/g. In reality, the arc energy also goes into heating of the arcing contacts and the surrounding air. An energy per evaporated mass of PTFE of 63.4 kJ/g is well below the TGA value, but is comparable to the arcing tests in [9]. Here, the tests were carried out with pure copper contacts and not copper tungsten contacts, which means that a significant part of the arcing energy probably went into evaporation of the arcing contacts and not only to the surrounding PTFE plates.

Both current interruption experiments result in significantly lower energies required to ablate the PTFE nozzle material than the case where the PTFE is heated uniformly until evaporated. This indicates that the stresses during arcing are clearly a dynamic process where e.g., local heating of the nozzle can cause small pieces or fragments of solid PTFE to break off. Thus, the TGA value is obviously not usable for estimating nozzle wear from arcing.

## 4. Conclusions

A test series of 100 consecutive current interruptions in a 24 kV/630 A "mainly active load" test duty have been carried out for a puffer-type LBS design. The contact and nozzle wear was monitored, as well as the development of the pressure build-up during the test series. The main findings are:

- ☐ All interruptions were successful at first or second CZ (that is, first CZ occuring with the pin contact outside the nozzle channel).
- ☐ The wear of the 7 mm diameter arcing contacts is not critical. Thus, a contact set of this size is believed to be acceptable for an MV LBS design with respect to wear during load current interruptions.
- ☐ The nozzle inner diameter increased from approximately 7.3 to 8.3 mm, or 14%. An increase in the nozzle-to-contact diameter ratio is not beneficial with respect to interruption capability, and could perhaps be a limiting design factor.
- ☐ The maximum pressure obtained in the puffer volume during both arcing and cold-flow measurements decreases with the number of interruptions.
- ☐ The pressure build-up is substantially higher when an arc is present. The maximum pressure in a cold-flow case is typically 0.6 bar over-pressure, while the maximum pressure for tests with arc can reach more than 1.0 bar over-pressure.
- ☐ A total of 31.7 kJ was dissipated by the arc during the 100 interruptions. Assuming that all the energy goes into nozzle ablation, this corresponds to a rate of 63.4 kJ/g. This value is significantly lower than found with TGA on this material.

## Acknowledgements

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