BACK-COMMUTATION AND STICKING REDUCTION METHODS IN DC CONTACTOR

Jakub Piska
Doctoral Degree Programme (1), FEEC BUT
E-mail: xpiska02@stud.feec.vutbr.cz

Supervised by: Jiri Valenta
E-mail: valentaj@feec.vutbr.cz

Abstract: The back-commutation and sticking are phenomena which cause an increase in time delay between arc ignition and arc reaching the arc chute. These effects cause increase in total switching time and contact and arc runner wear. This paper gives a comparison of several approaches to reduction of these effects in a medium voltage contactor for traction usage. The three chosen approaches were: changes of the shape of the arcrunners, changes of the pole plates of the magnetic circuit and increase of the ventilation cross section. Metrics on how to compare the performance of these different alterations were given, based on switching times. From the three tested methods the ventilation increase yielded the best results as it both reduced the switching time and time delay caused by the back-commutation and reduced the variation of these characteristics.

Keywords: Contactor, breaking, back-commutation, sticking, reignition

1 INTRODUCTION

The arc extinguishing mechanism in the majority of DC contactors is magnetic blow-out. This method uses magnetic field to push the arc into an arc chute which by the means of cooling and arc prolongation increase the arc voltage and thus help the breaking process. This magnetic field can be created by several means - shape of the current path, addition of coils or permanent magnets. The goal is to transfer the arc into the arc chute as quickly as possible. This is because without the arc voltage exceeding the source voltage the arc cannot be distinguished in a DC circuit.

However, the transfer process is often hindered by effects like back-commutation and sticking. This is because the arc motion is not determined only by the external forces like magnetic force, pressure of surrounding gasses and fluid resistance. The arc tries to assume a position with the lowest arc voltage possible and often stays in places where the increase in voltage would be significant. These places are most commonly located on original contacts, just before arc chute and in places where arc-runners diverge. The arc staying in this position is called *sticking*. In case the arc moves past these places another phenomenon called *back-commutation* can occur. This is because the arc leaves behind it a space filled with ionised gas and after the arc voltage increases, again due to increasing its length, another parallel arc is ignited in the ionised vapours. This new arc is shorter and thus has lower voltage and as they are parallel, the original arc decays. After that we are left with a new arc in a position further from arc chute. Both of these effects significantly increase the total switching time and thus increase the thermal strain on the contactor which lowers the expected service life of the contactor.[1] There have been proposed many ways to alter a switching device to decrease the influence of these reignition effects. Some promising ones were tested in this paper.

2 METHODOLOGY

A way to quantify the results of the breaking tests was needed. A system of three times is used - t_1, t_2, t_d. t_1 is the total switching time, measured from the first increase in arc voltage to current zero. t_2 is travel time to the arc chute, measured from first increase in arc voltage to the first peak, which coincides with arc entering the arc chute. This fact was determined by comparing the arc voltage data and fast camera recordings. Lastly t_d is the sum of time delays caused by arc stagnation and back-commutations. These delays were defined as the time needed for the arc voltage after back-commutation to reach its original value before the back-commutation as shown in fig.(1). The software used disregarded any delay that was shorter than 100 μs. This was done because these delays of shorter length are a normal part of any arc voltage signal and bear no connection to back-commutation or sticking.

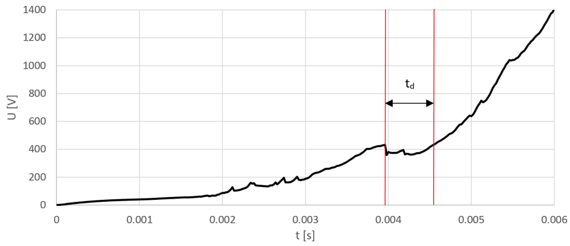

Figure 1: Back-commutation delay

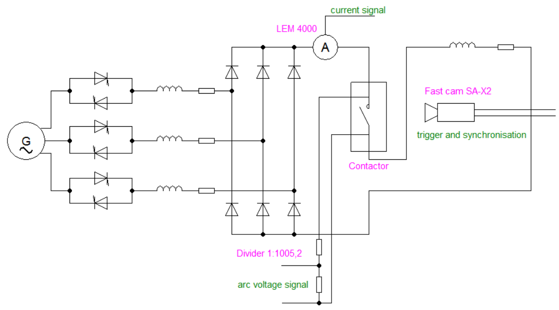

Figure 2: Measurement setup

3 EXPERIMENTAL SETUP AND TESTED DEVICE

The test circuit is shown in fig.(2). All tests were conducted with parameters 2250 V, 960 A, time constant 8.6 ms. These parameters were chosen as they coincide with the limits of switching capability of the tested contactor. Each sequence of tests was conducted as a series of 10 test with one alteration. There was always a 5 minute break between each test. This was done, so the contactor would not overheat. After each series the ceramic plates from arc chute were replaced as their degradation is the main reason for worsening of the contactor switching performance.

4 ALTERATIONS

Other authors have presented several possible solution to the reignition problems. [2] and [3] have investigated the influence of contact materials, [2] and [4] have tried altering the width and material of the contact chamber and [5] have swapped the splitter plates for a narrow slot with a great success. All of these solutions, while somewhat effective are unsuitable for alteration of already existing device.

One of easily realisable implementations is given by [3] and [6] who investigated the influence of venting condition on arc movement by opening or choking the exhausts which can be implemented in three ways - covering the exhausts, changing the shape of the ceramic plates or by removing some of the ceramic plates. The last method unfortunately leads to lower arc voltage which is detrimental to breaking process as a whole. Both authors measured the lowest travel time with maximally open vents. The second mentioned option was chosen for further tests. The ventilation area was increased from 880 mm^2 to 1540 mm^2. This is shown in fig.(3)

[7] gives another alteration which leads both to shortening the travel time and reduction of the amount of back-commutations - changing the shape of arcrunners. [7] tested several arcrunners which opening

angles from 60 to 150° and the number of back-commutations only increased with the opening angle. As can be seen from fig.(5) the original construction has a sharp increase of arcrunner distance as the arc passes from lower arcrunner to the upper. This was changed so the arcrunner distance is more gradual.

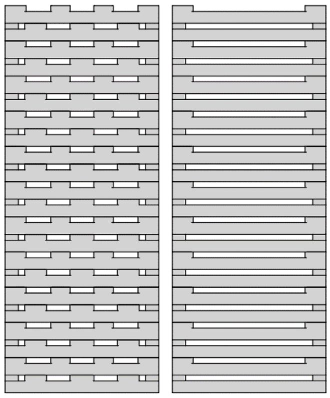

Figure 3: Ventilation alteration

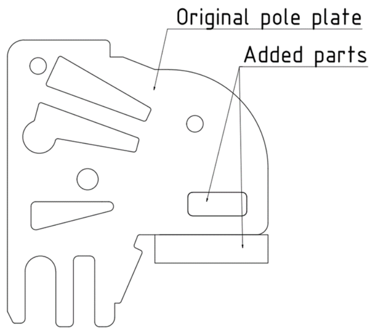

Figure 4: Pole plate alterations

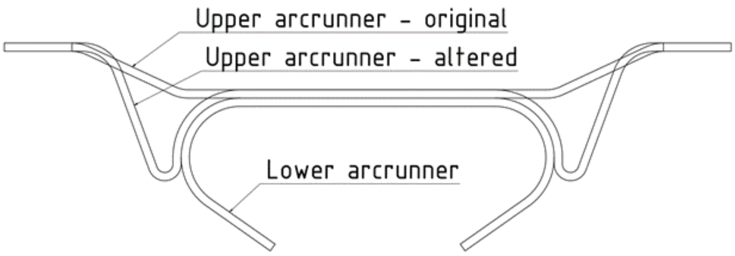

Figure 5: Arcrunner alterations

And as could be expected, changing the magnetic field so it is increased in the places where arc stagnation and back-commutation occur leads to lowering of the total travel time as shown by [8]. For this the pole plates of the magnetic circuit were altered so the magnetic field between the contacts was increased from average magnetic flux denstity 16.4 μT to 17.2 μT. This was done by adding two iron parts to the original pole plates as can be seen in fig.(4). This change can lead to a negative effect of decreasing the magnetic field in the arc chute and thus lowering the arc voltage. This would in turn prolong the total switching time. The values were calculated in Ansys as an average magnetic flux in the volume between fully opened contacts. The calculation was done as magnetostatic with permanet magnets as the only source of magnetic field.

5 RESULTS AND DISCUSSION

To determine whether there was any significant change in behaviour of the contactor independent two sample t-tests at significance level of 5% were done on the average values and variations of the results. The comparison was always done against the results of the measurement with no changes. The t-tests for altered arc runner were done as t-tests with unequal variances. T-tests for pole plate and ventilation alterations were done as t-tests with similar variances.

The only set of data which was not found significantly different was the total time t_1 for pole plate alteration. After establishing that the differences in data are not due to fluctuations, the results can be compared.

No change			Arc runner			Pole plate			Ventilation		
t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]
21.70	7.36	3.32	19.42	6.14	2.14	21.38	6.62	2.44	20.08	6.62	2.86
22.33	7.04	2.54	21.20	6.60	2.40	21.90	6.66	2.40	20.66	6.76	2.68
23.16	8.22	3.54	20.72	5.92	2.32	21.70	6.94	2.54	21.14	5.96	2.06
22.20	6.46	2.96	22.02	7.00	2.44	22.52	7.20	2.96	21.58	6.04	2.10
23.16	8.04	3.36	22.54	8.28	4.10	23.00	6.58	2.62	21.38	6.38	2.46
23.44	7.48	3.22	22.04	6.28	1.80	22.52	6.06	1.84	21.20	6.04	1.88
22.98	6.84	3.04	21.86	6.66	2.58	22.88	6.38	2.20	21.94	6.90	2.50
22.90	6.98	2.40	22.66	7.24	2.60	26.46	7.94	3.62	21.72	6.00	2.00
24.86	7.56	3.10	22.36	6.84	2.46	23.26	6.67	2.62	21.82	6.34	2.24
22.74	7.00	2.54	22.42	7.26	3.06	23.84	7.34	3.00	21.70	6.12	1.96

Table 1: Measured data

	No change			Arc runner			Pole plate			Ventilation		
	t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]	t_1[ms]	t_2[ms]	t_d[ms]
E(X)	22.95	7.30	3.00	21.72	6.82	2.59	22.95	6.84	2.62	21.32	6.32	2.27
s(X)	0.65	0.27	0.14	0.92	0.42	0.35	1.87	0.26	0.21	0.30	0.11	0.10

Table 2: Average values and standard deviations

	Δt_1[%]			Δt_2[%]			Δt_d[%]		
	AR	PP	VEN	AR	PP	VEN	AR	PP	VEN
E(X)	-5.3	0.0	-7.1	-6.5	-6.3	-13.5	-13.7	-12.6	-24.3
s(X)	41.2	186.5	-53.6	56.0	-2.9	-60.6	154.0	55.8	-26.9

Table 3: Changes in switching times t_1, t_2, t_d

As can be seen from tab.(3) all of the alterations lower the back-commutation and sticking effects. In case of arc runner and ventilation this leads to the lowering of total switching time. In case of pole plates this does not occur due to the lower magnetic field at the ceramic plates which leads to a smaller prolongation of arc and lower arc voltage.

The most significant effect was that of the increasing of the ventilation cross section. This alteration even positively affected the variation of the switching times which increased with the other two types alterations.

6 CONCLUSION

1. The mechanisms of back-commutation and sticking in switching devices were described.
2. Three metrics were suggested for comparing different switching operations: total switching time, arc travel time and time delay caused by back-commutations.
3. Three method how to reduce the back-commutation and sticking suggested by other authors were tested on a middle voltage contactor for traction usage: Shaping the arcrunners so there are no sudden increases in arc length. Shaping the pole plates of magnetic circuit so the magnetic field is increased between the original contacts. Increasing the ventilation cross section by changing the shape of ceramic plates in the arc chute.
4. Series of 10 tests were done on each alteration and were compared to the original construction.
5. All of the alteration yielded positive results as all of the metrics only decreased. The most promising results were of the increasing of ventilation cross section. This has both decreased the back-commutation delay by 24 % and also lowered the variation of the measured times.

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