RELIABILITY OF MECHANICAL CONNECTORS FOR MEDIUM VOLTAGE CABLES

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ABSTRACT

The use of mechanical connectors for medium voltage cable accessories becomes more and more frequent and there are very less experiences concerning the long-term behaviour of this type of connectors. The paper presents the results of investigations according to the valid connector standard /1/ for the different construction features. From the results conclusions were drawn for the design of mechanical connectors and their expected long-term reliability.

INTRODUCTION

Since the substitution of medium voltage paper cables by polymeric cables a highly increasing number of different cable types are used in Europe. Figure 1 shows only 7 of more than hundred MV cable constructions. To connect these cables with different conductor material, -shapes and cross sections, mechanical connectors are a good solution to these technical demands. In recent years a variety of mechanical connector designs had been established in the market (see as well Figure 1).

Figure 1 Few Representatives of MV cables and mechanical connectors

The reliability of those connectors depends on the following parameters:

- connector material and surface treatment
- design of the contact support
- bolt material, diameter and head design of the bolt
- conductor material, shape and cross section
- number of bolts
- fastening torque and contact pressure
- connector dimensions and positioning of bolts

At the University of Applied Sciences in Zittau the main design features and their mutual dependence were under examination in long-term experiments and detail tests for the above mentioned parameters.

DESIGN VARIANTS

Figure 2 presents only some design differences of 4 frequently used connectors in the market.

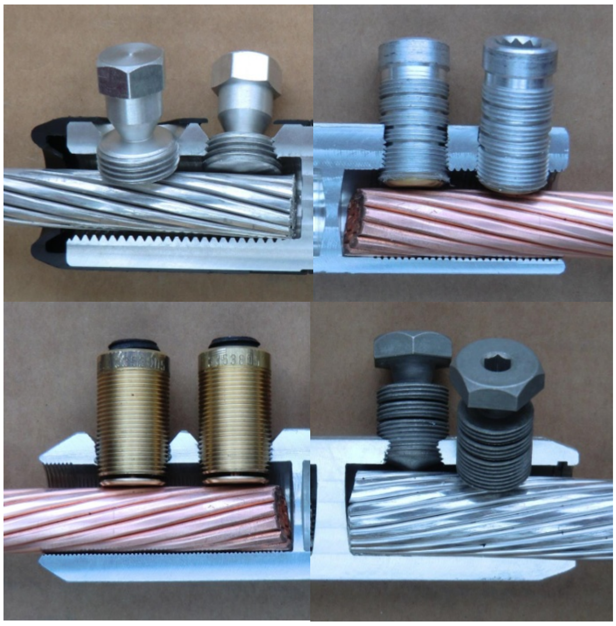

Figure 2 Design differences of 4 representative connector types

The main advantage of all these connectors is a wide cross section range (for example from 50 to 240 mm²) for aluminium and copper conductors. There is no special crimping tool required and installation mistakes by not using the appropriate crimping insert is nearly impossible.

Connector material and surface treatment

The connector material for LV and MV connectors is aluminium or aluminium alloy. To avoid an oxide layer with a high contact resistance, the surface of connectors is in general tin-plated. The contact area for the conductor is grooved longitudinal or transverse to the conductor (see Figure 2) to establish a great number of micro contacts and to destroy the oxide layer of aluminium conductors.

Bolt design and material

The bolt design is very important for the reliability and that's why and also for patent reasons there are a very large number of different bolt designs in use. Figure 3 presents only some of these solutions. Most of these bolts are shear bolts with a very special construction to guaranty that there is no excess length over the outer diameter of the connector after installation.

Figure 3 Variants of bolts

Installation requirements

Besides a wide cross section range a connector used in MV joints should fulfil the following requirements:

- No special tool for installation (like a torque wrench)
- No excess length of the bolts after installation (may create damages by use of slip on joints)
- Not to high rupture torque of the bolts (requires a compromise between good contact resistance and muscle shock for the jointer)

CONTACT RESISTANCE

A very low contact resistance is the main condition for a long life time of a connector and can be influenced by the current distribution in the connector, by the material combinations between the connector, the bolt and the conductor and by the clamping torque of the bolts.

Current distribution inside the connector

There are two main contact-areas between conductor and connector like shown in Figure 4. Depending on the resistances the current splits in a fraction through the bolt to the connector tube and a fraction directly through the connector tube (see Figure 5).

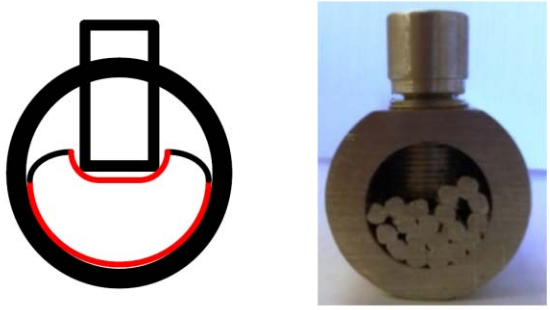

Figure 4 Main contact areas (red)

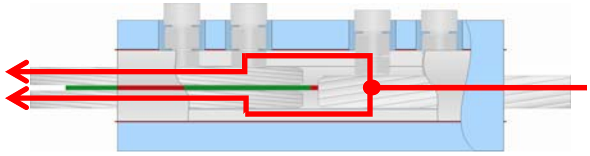

Figure 5 Measurement set up for the current distribution inside the connector

It was shown by different measurements that the current divides in a ratio of nearly 1:1 to the two possible ways of transmission. This division has been studied in an arrangement with a 150mm² solid sector shaped conductor. Variations with different bolt diameters and bolt materials and furthermore different conductor forms and conductor materials are currently under investigation.
These investigations are essential to draw conclusions on the dependence of the connector-dimensions from the connector bolt construction (e.g. material, diameter, torque). The recent results lead to the assumption that the bolt as a functional transmission component should be included in the connector-dimensioning.

Clamping torque and contact resistance

The tightening or clamping torque of the bolt has a high influence on the connector resistance. If the torque is too low, it may cause malfunction of the connector in consequence of an increasing resistance during operation (see the high temperature in Figure 7). The same problem can occur if the tightening torque is too high especially with stranded aluminium conductors due to the damage of single wires. Furthermore a high torque is difficult to control for the jointer.
Subject of one of the fundamental investigations was a connector with four bolts and a nominal torque of 34 Nm mounted on a stranded aluminium conductor of 150 mm². The connector resistances were studied at steps of 30%, 60%, 100% and 130% of the nominal torque (see Table 1 and Figure 6). Based on /1/ the circuits were subjected to a load cycle test.

Torque [Nm]	Torque [%]	C1	C2	C3	C4	C5	C6	C7	C8
34 Nm = 100%		Rj [µΩ]	Rj [µΩ]	Rj [µΩ]	Rj [µΩ]	Rj [µΩ]	Rj [µΩ]	Rj [µΩ]	Rj [µΩ]
5	14,7	68	105	109	52	62	54	53	42
7	20,6	49	99	89	45	54	49	39	38
10	29,4	36	78	68	34	37	40	31	33
14	41,2			47	30	30	34	28	29
17	50			35	28	28	32	28	27
20	58,8			32	26	27	30	26	25
24	70,6					26	29	24	24
27	79,4					25	29	24	23
30	88,2					25	27	23	23
33	97,1					24	26	23	22
37	108,8							22	21
40	117,6							22	21
43	126,5							21	21

Table 1 Clamping torque and contact resistance

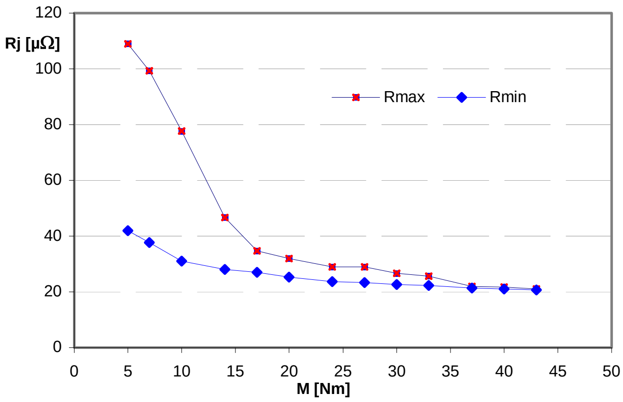

Figure 6 Range between minimum and maximum contact resistance as a function of the clamping torque

A low tightening torque may cause a high connector resistance. After 45 load cycles at a load current of 500 A (which cause a temperature of the reference conductor of 140°C) leads to very different connector temperatures in dependence on the tightening torque. One connector tightened with 30% of the nominal torque reached a

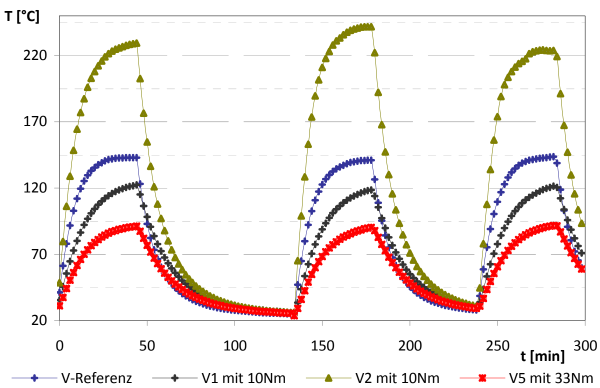

Figure 7 Temperature of reference conductor and connectors with different clamping torque during load cycling test

temperature of 220°C, well above the reference conductor temperature (see Figure 7). A second connector with the same torque reached only 120°C and the connector with the nominal torque reached less than 100°C. The connector with the temperature of 220°C further showed a fluctuating behaviour with regard to the resistance, which is a clear sign for a malfunction. Actual the circuit is in a long time load cycle test in order to study what happens within the connectors with bolt-tightening torques above and below the nominal tightening torque.

Material combinations and contact resistance

Probably the bolt affects not only to exert pressure but also to carry a greater influence on the contact resistance due to its direct contact to the conductor. Material and shape of the bolt must be chosen in a way that the contact resistances along the bolt are as small as possible.
In order to that some examinations with different material variations were performed. Therefor a device was used as shown in Figure 8.

1. DC source
2. Voltmeter
3. Fixed contact
4. Moveable contact
5. Tensioning screw
6. Tensioning spring
7. Force meter
8. Micro voltmeter
9. Shunt

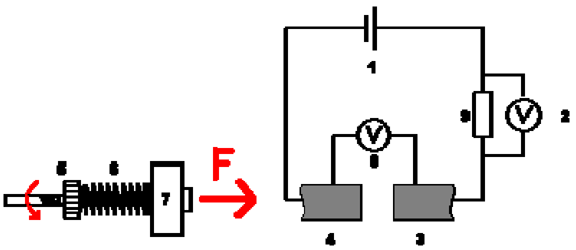

Figure 8 Measurement set up for the contact resistance as a function of contact pressure and photo of contact piece samples

With a spring (6) a force is applied to contact pieces (3+4). The force is measured by a load cell (7). The potential difference at the interface of the contact pieces (3+4) is measured by a voltmeter (8) and the current by shunt and a voltmeter (2+9).
The Results for the most important material combinations in a connector between conductor and connector tube on one hand and the bolts on the other hand and between the bolts and the connector tube are shown in Figure 9.
The contact force was increased in a range from 20 to 250 N for contac pieces with different diameters to get a contact pressure from 0,4 to 5 N/mm². Figure 9 shows the measured contact resistance between the contact pieces for a diameter of d = 8 mm and d = 12 mm.
It was shown that a contact pair aluminium/copper

reaches a similarly low level of contact resistance as a contact pair copper/copper. Especially for low contact forces the resistance of a pair aluminium/aluminium is higher by a factor of 3 than a pair copper/aluminium. The contact resistance of a pair aluminium/brass is nearly in the middle of the mentioned other contact pairs.

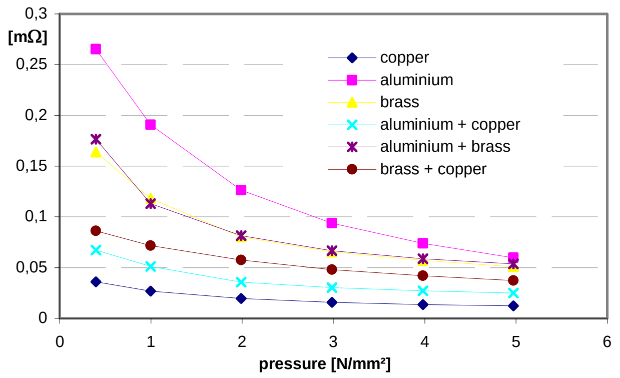

Figure 9 Contact resistances of material combinations as a function of contact pressure

The Results of this investigation, which is still in progress, can be used in the future to define design guidelines for an optimal combination of different bolt materials.

RELIABILITY REQUIREMENTS AND LONG TERME BEHAVIOUR

The tests of mechanical connectors according to /1/ allow up to now only few general predictions for the long term reliability of these connectors.
The investigation of the contact resistance for different material combinations (see Figure 9) allows the conclusion that for all considered connectors and copper conductors there is no problem concerning long term reliability.
More difficult is a clear conclusion for aluminum conductors. In this case the contact resistance is much higher and there is the special problem of aluminum to yield under pressure, which leads to an increasing resistance. Given that the contact life time depends considerably from the initial value of the contact resistance a shorter life time will be expected for the same connectors with conductors of aluminum.
But investigations presented two years ago in /2/ have shown that connectors and aluminum conductors behave even in case of critical load and overload excellent.
The advantage in medium voltage distribution networks is furthermore, that the load conditions are much less than 50 % of nominal load.
Investigations for overhead line connectors in /3/ have shown, that the connector life time increase considerably (in the range of factor 2 to 3) if the load is less than the nominal load.

CONCLUSION AND OUTLOOK

Under consideration of a steady increasing number of medium voltage cable variants there is no reasonable alternative to mechanical shear bolt connectors.
A general conclusion for these connectors especially for aluminium conductors is not possible after that only limited number of long term tests, but the failure risk even for connectors with aluminium conductors is negligible or marginal. To give a more accurate prediction of life time the complex ageing mechanism of different connector and conductor materials requires more studies in this field.

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