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SOME CONSIDERATIONS CONCERNING COMPOSITE INSULATORS DESIGN

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Abstract – This paper deals with some of important items regarding the problem of design of composite insulators for use in HV outdoor applications. Taking into account the fact that principal designs currently in use may differ in design details such as the moulding lines position in respect to the main direction of the electrical field and the design of the joint between housing and end fittings, making differences in their performance, those two important items were discussed using the support of the software developed on the base of the Bosnian algebra approach.

Keywords: composite insulators, design, moulding lines, and interfaces

1. INTRODUCTION

Polymer materials such as silicone elastomers, hydrocarbon elastomers and epoxy resins are being increasingly used instead of porcelain and glass for outdoor insulation applications such as line insulators, bushings, hollow core insulators, cable terminations, etc., chiefly due to the following advantages [1]:

- Light weight = lower construction and transportation costs;
- Vandalism resistance = less gunshot damage;
- High strength to weight ratio = longer spans/new tower design;
- Improved transmission line aesthetics;
- Unexplosive housing = improved safety of the working people in the station and for the installation equipment.

Unlike porcelain and glass these polymers have low surface free energy which makes the virgin surface (new and without exposure to the environment) of the polymers inherently hydrophobic (water repellent). Hydrophobic surfaces present a higher resistance to leakage current flow than porcelain or glass surfaces (hydrophilic surfaces) and require higher current and commensurate energy dissipation to initiate the well known phenomenon of dry band arcing which, ultimately, is responsible for material degradation in the form of tracking and erosion. The lower leakage current and consecutive lower probability of dry band formation require a higher applied voltage to cause flashover, in one word, due to the hydrophobic surface, the polymer materials typically offer much better contamination performance over porcelain and glass, when aged [2].

Service stresses, such as surface discharge activity on hydrophobic surface, UV exposure and chemical attack, cause the reduction or complete loss of hydrophobicity and dry band formation under the same process as porcelain or glass. It has been observed that, in case of silicone rubber, the surface, due to the diffusion of mobile low molecular polymer chains (LMW) from the bulk to the surface [3] and the rotation of surface hydrophilic groups away from the surface [4], recovers hydrophobicity when there is little or no dry band arcing for several hors [5].

The ability of the material to control leakage current, which represent the first defence line of insulating device, varies significantly depending on polymer material used, but also on its interaction with the product design. However, even housing materials that have a tendency to recover its lost hydrophobicity must be able to withstand dry band arcing without tracking or erosion – a secondary line of defence against contamination - induced flashover. Housing design can also influence leakage current during the periods of reduced or lost hydrophobicity. Therefore the key to longevity in polymeric (nonceramic or composite) insulators is to ensure that leakage current is kept low. Housing material formulation and leakage current path design are two interdependent tools that manufacturers have available to solve performance optimisation problem. Moreover, design weaknesses (lack of voltage stress relief, poor sealing between materials and connecting hardware, improper method of attacking fittings) as well as quality control problems have very important, probably a primary role, in determining the life of these insulators. As we just sad, polymer materials usually outperform porcelain and glass in contaminated environments, but must be adequately designed and manufactured to withstand such conditions without accelerated ageing (in dry and non - contaminated environments, these insulators normally have a very long life) .

To summarise our earlier discussion showing that housing polymer formulation, product design and manufacturing process are interdependent and that manufacturer, in order to offer a good insulator, has to solve the higher order optimisation equation, we shall use our extension [6] of a matrix developed by Prof. H. Kärner [7] – Fig. 1.

		Insulator	
		bad	god
bad	bad	normal	impossible
bad	good	normal	impossible
good	bad	normal	impossible
good	good	possible	NEEDS KNOW-HOW
Design	Material		

Fig. 1. Interdependence matrix in composite insulator production

As we can see, producing a bad insulator from a poor material is quite normal as well as from a good material, if we have a bad design, while making a good insulator from a poor material, even in case of a good design, is virtually impossible. However, even if one starts with a good material, there is still possibility of manufacturing a bad insulator if the design is poor. Finally, one can produce a bad insulators starting with a good material and having good design if there is not available KNOW-HOW – poor manufacturing process and/or poor quality control. Obviously, a good composite insulator could be obtained in case of a perfect combination of design and polymer material formulation. To transfer the "could" to "can", the third conditions has to be fulfilled – manufacturer's know-how.

This paper deals only with the some aspects of design, which also influence on housing material behaviour, as well as on the interfaces presented in currently used design of composite insulators.

2. MAIN DESIGNS CONTEMPORARY IN USE

Fig. 2 shows three principal designs of composite insulators. Insulators acc. to Fig. 2a consist of a fibre reinforced polymer (FRP) rod (tube in case of hollow insulators) covered with a seamless sheath. The sheath is applied by an extrusion process used in manufacturing of cables. For the reason of bonding, a primer is applied to the rod surface prior to extrusion, enabling the sheath to obtain chemical crosslinking to the rod surface. The sheds are moulded separately in two partite moulds, and pushed onto the sheath by means of a slippery vulcanising paste. When the requested number of sheds are positioned as designed, sheds and sheath are vulcanised together at elevated temperatures (HVT – high temperature vulcanisation). The bonding between fittings and housing is realised using a metastable silicone rubber sealing.

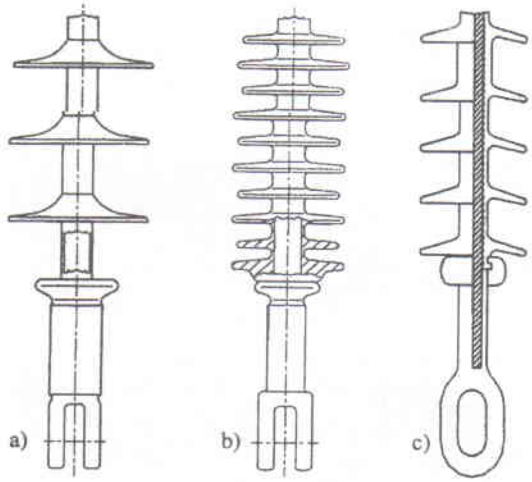


Fig. 2. Three principal design of composite insulators

Insulators acc. to Fig 2b are produced in a single shot moulding process where FRP rod is positioned between two halves of a parted mould and the housing (including at the same time the sheds) material is injected into the mould. After heating the vulcanising process starts to crosslink the housing materials as well as the bond between housing and the rod surface. When a stable state of housing material is reached, the mould is opened and insulating body is taken out.

The design of composite insulators acc. to Fig. 2c uses modular weathershed housings including up to 16 weathershed in a single module. The modules are then mechanically bonded to the adjacent module by an external polymer collar. The modules are mechanically sealed to the end fittings within an integral grading disk. The modules are assembled to the rod using a high dielectric strength silicone compound in the interface. The silicone compound is held in place by internal o-rings moulded into weathershed housing.

All of tree designs are in close connection with the manufacturing process which makes various technical and economic advantages and disadvantages distinguishing them.

3. MOULDING LINE AND ITS POSITION

A decisive design item which makes difference between principal designs is the moulding line and its position derived from the moulding process. The design acc. to Fig. 2a results in no moulding line along the insulator shank between the sheds. The sheds themselves show moulding line at the outer periphery of the sheds. These moulding lines are arranged perpendicular to the main direction of the electrical field. The designs acc. to Fig. 2b and 2c result in moulding lines on all sheds as well as on the insulator shank. Those moulding lines are arranged parallel to the main direction of the electrical field.

Long term service experience [8] as well as laboratory experiments [9, 10] show general weakness of moulding lines running parallel to the electric field: at first the moulding lines change colour and increase surface roughness; in the second phase further blacking occurs in the surroundings of the moulding lines indicating that the moulding line material is different to the bulk material (dispersion in filler uniformity confirmed in [9]; at the third stage the first chalking, erosion and cracking occur at the moulding line – Fig. 3. The progress of the erosion process may at the end lead to core exposure resulting in a line drop.

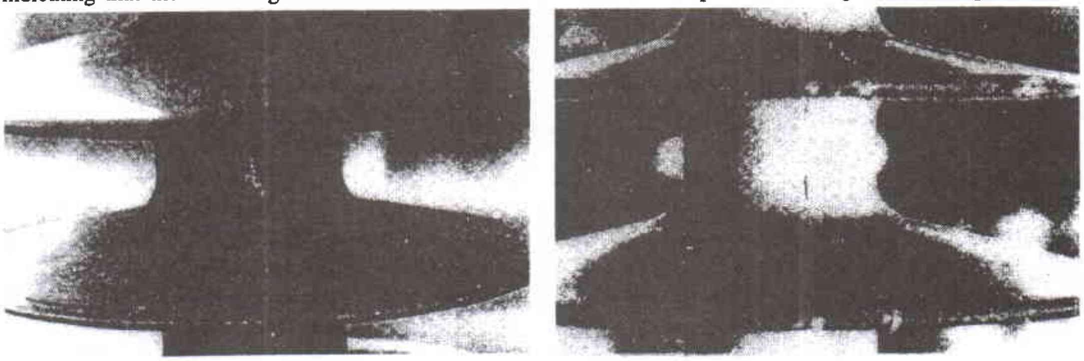
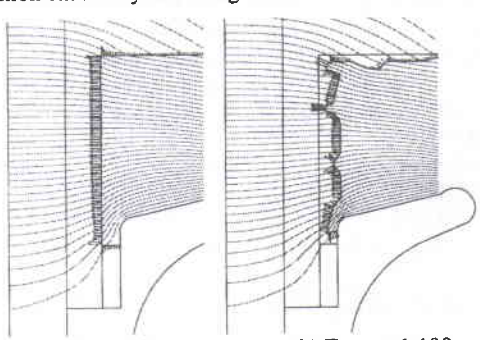


Fig. 3. Two examples of erosion and cracking in the moulding line between sheds on EPDM insulators after long duration tests.

In order to remove the moulding lines (caused by excessive housing material moving between the two parts of the mould towards the outside) a scrutinised technique is required (housing must not be hurt), which is not easy to be performed in case of the design from the Fig. 2b and 2c. The observed problems of ageing of housing caused by existence of moulding lines running parallel to the main field directions could be explained by the fact that the lines itself cause significant distortion of electrical field distribution – increase of its tangential component.

Fig. 4 shows an example of electrical field distribution caused by moulding lines.



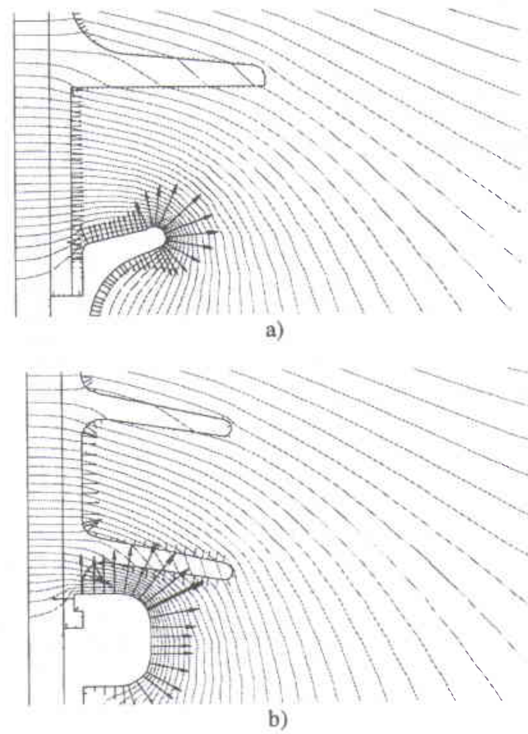
a) $E_{tanmax}=1$ b) $E_{tanmax}=1.198$

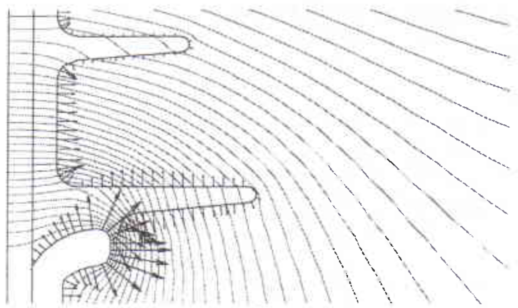
Fig. 4. Simplified model showing distortion of electrical field caused by moulding lines a) without moulding lines, b) with moulding lines Note: tangential components of the field are turned by 90° because of better visualisation [6]

4. DESIGN OF THE TRIPLE JUNCTION

The design of the interface between the metal end fittings and organic polymer of the housing is a very sensible item of composite insulator design, simply because of the fact that the design of this part has a decisive influence on the behaviour of partial arc staring from the triple junction point. In case of design where the point of the highest field strength and the triple junction point are the same point (Fig. 2b), a partial arc ignited at the triple junction point (dry band fashovered in vicinity of the lower end fitting) will have this point as a stabile foot-point causing burning and erosion of the isolating material at the triple junction point.

In case of the design from Fig. 2a and 2c, the triple junction point is not the point of the highest field strength – Fig. 5.





c)

Fig. 5. Calculated field distribution for different designs currently in use. Note: tangential components of electrical field are turned by 90° because of better visualisation [6]

Therefore, the foot-point of the partial arc ignited at the triple junction point will be moved do the point of highest electric field strength meaning that the design itself, causing the partial arcs instability, secure protection of the interface between isolating housing and metal end fitting.

Apart from a electrical aspect of different design of triple junction discussed here, where we, using electrical field distribution calculations confirmed the consideration given in [11], it is important to emphasise also the mechanical aspect discussed in more detail in above mentioned paper. Namely, in case of a rigid connection of housing, metal and rod to each other (very different modules of elasticity and different coefficients of thermal expansion), mechanical stresses will occur unavoidably in the interfaces in case of temperature changes and mechanical loading – designs from Fig. 2b and 2c – a tremendous shear stress results in the interfaces of the materials involved. Proper choice of an additional material (sealing material) in the case of design from Fig. 2a could bring a design where all mechanical stresses in the interfaces are eliminated.

5. CONCLUSIONS

1. Housing polymer formulation, product design and manufacturing process are interdependent and in order to obtain a good insulator a manufacturer has to solve the higher order optimisation equation: a good composite insulator could be obtained in case of perfect combination of design and polymer formulation, but the third condition has to be also fulfilled – manufacturer's know-how.

2. A decisive item which makes difference between principal designs are the moulding lines ant their position. The moulding lines running parallel to the main field direction could bring about electrical field distortion causing chalking, erosion and cracking of polymer housing which may at the end lead to serious problems resulting in line drop.

3. The field intensity near the triple junction (housing, air and metal) must be controlled (by design) in such a way that partial arcs anchoring at the interface between housing and metal is prevented – the design of end fittings and position of triple junction ought to provide for instability of the partial arcs burning from triple junction point.

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