ROLE OF SURFACE TO VOLUME RATIO OF ZINC OXIDE ARRESTER ON ENERGY ABSORPTION CAPABILITY

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Abstract: Functional life of a zinc oxide arrester block is largely dependent on its energy absorption capability which is an important characteristic in ensuring enhanced reliability of a surge protection system. An arrester block is usually cylindrical in shape with two flat surfaces. Injected energy from the stroke of transient electrical surge into the arrester body is transformed into heat and dissipated through the surface of the disc body. This study has been conducted to observe whether the higher surface to volume (S/V) ratio of an arrester block enhances the capability of energy absorption or not. The round side or C-surface of the cylindrical disc was ground by diamond wheel to transform into hexagonal shape. By making this geometrical modification an increase of about 11% in S/V ratio was achieved for the hexagonal discs. Ten ZnO arrester blocks of both shapes were tested and the average energy absorption capability for the hexagonal discs was found to be 483 $J.cm^{-3}$ compared to that of 357 $J.cm^{-3}$ for the cylindrical discs. Thus, for the hexagonal discs a significant increase (35%) in energy absorption capability is observed which is attributable to increased S/V ratio of the arrester facilitating greater heat transfer. This knowledge can be useful in designing the geometry of the device for improved functional reliability of electrical system.

Key words- ZnO arrester block, Energy absorption capability, surface-to-volume ratio, failure mode

I. INTRODUCTION

Zinc oxide varistors are electronic ceramic devices, the primary function of which is to protect the electrical systems by sensing and limiting transient surges [1]. Application of this metal-oxide varistor technology is very common now-a-days for voltage stabilization or transient surge suppression in electronic circuits and electrical power systems [2-5]. Owing to the improvements of non-ohmic properties and functional reliability, use of ZnO varistors is expanding quite rapidly. Moreover, with the advent of advanced manufacturing technology, varistors having new designs and configurations are expected to have wider application.

In addition to some finishing operations, varistor manufacture basically follows the route of conventional ceramic processing. Compared to the long history of ceramic materials, use of electronic ceramic as transient over-voltage suppression device is a recent development [6]. Performance and reliability of electronic ceramic depends on the grain and the grain boundary phenomena [7- 8]. There are various investigations on particle size distribution on physical, mechanical and electrical properties of ZnO varistors [9-13]. The use of binder is very crucial in the processing of electro ceramics. The effect of latex binders is also investigated and it has been observed that binders significantly affect the physical, mechanical and electrical properties of varistor discs [14]. In varistor fabrication a passivation is applied on the peripheral surface of the discs to provide a collar material which acts primarily as a barrier to flash over. Investigation on the influence of passivation on the energy absorption capability thickness revealed very little impact; though the mode of failure was changed [15].

A Processing of arrester block

Zinc Oxide varistors produced in the form of cylindrical blocks are often called arrester blocks. The spray dried powder in the form of granulates was compressed into disc-shaped blocks with approximately 55 to 65 percent of their theoretical density. Pressing was performed by uniaxial double action compaction technique. Sintering of the discs was performed by a conventional sintering profile with a peak temperature of about 1120 °C and a total sintering cycle time of about 70 hours. The sintered ceramic body takes the shape of a rigid cylinder with a theoretical density of more than 95 percent. ZnO varistors undergo a liquid phase sintering. During this process, the bismuth oxide melts to form the liquid phase which dissolves, at least in part, the other doping substances and promotes their uniform distribution. Liquid phase also favors the grain growth and dense sintering. Spinel precipitates, on the other hand, inhibit grain growth and help generate a uniform distribution of the ZnO grain size.

Researches in the varistor technology have been primarily aimed at improving the fundamental properties. In this regard much of the work is related to the investigation of material composition, micro-structure, whilst grain and grain boundary phenomenon and defects [16-21] got the maximum attention. Work investigating the effect of Surface to volume ratio on the ZnO varistor properties especially in the context of energy absorption capability has not been reported. This experiment was conducted to check the effect of the surface to volume ratio of the arrester block on the energy absorption capability.

II EXPERIMENTAL PROCEDURE

A Preparation of samples of hexagonal discs

The shape of hexagonal cross-section was achieved by modifying the C-surface of the cylindrical discs as shown in Figure 1.

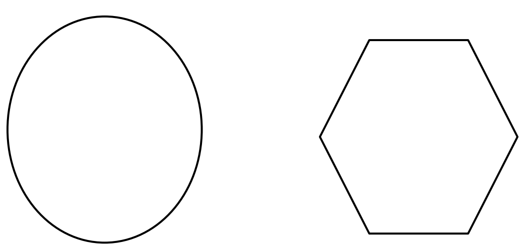

Figure 1: The circular cross-section of a cylindrical disc made hexagonal following the grinding operation.

Material was removed by using a production-line diamond grinding wheel rotated along a vertical axis. ZnO cylindrical arrester discs were passed under the flat face of the diamond wheel by placing them horizontally on the conveyor belt. A small depth of cut was used to remove material in one pass requiring several passes to complete one of the six flat sides of the hexagonal discs. After one flat plane was obtained, the other two adjacent flat surfaces were developed at angle of 60 degree relative to it. The remaining three flat surfaces were ground one by one by placing the disc on the conveyor belt making contact with the already developed flat surfaces. A cylindrical disc was transformed into a hexagonal shape as shown in Figure 2 by progressively generating all the six flat surfaces.

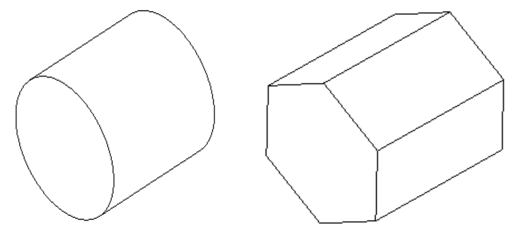

Figure 2: Disc of hexagonal shape as obtained by grinding the cylindrical arrester block.

A cylindrical disc having diameter of 41 mm had a cross-section of 13.2025 cm^2 and the cross-section for a hexagonal disc was reduced to 10.9184 cm^2. Since the disc height of 42 mm remained unchanged, the volumes of the cylindrical and hexagonal discs became 55.45 cm^3 and 45.86 cm^3 respectively with the corresponding values of surface areas of 80.5032 cm^2 and 73.7887 cm^2. The As a result the S/V ratio of hexagonal disc is increased to a value 1.609 cm^{-1} compared to the value for the cylindrical disc of 1.452 cm^{-1}. Thus by making the modification of the cylindrical disc into hexagonal shape an increase of about 11% in S/V ratio was achieved for the hexagonal discs.

B Evaluation of Energy absorption capability

Energy absorption capability of a varistor is determined by the maximum energy density injected into the ceramic body up to which it can sustain for a cycle of three shots. The test is initiated with a lower charging voltage so that injected energy remains in the range of about 200 Joule.cm^{-3}. Selection of the lower starting range of energy is attempted to keep the likelihood of failure at the first cycle to a minimum level. Thus the sample size reduces progressively as the disc fails step by step with the increment of charging voltage. The testing procedure was continued until all the discs failed at a certain stage. Energy density of a disc is calculated by using the clamping voltage and the peak current recorded from the cycle of three shots. In Figure 3 the long wave shape for energy testing is presented.

C. Calculation of Injected Energy per

Energy injected by a pulse is the integrated value of the product of the voltage and current passing through the disc over the pulse duration. So the amount of energy can be expressed mathematically with the following relationship:

$$Energy = \int_0^t vidt \qquad (1)$$

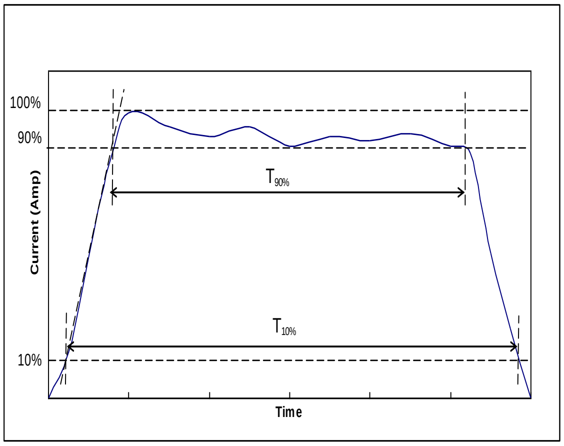

Figure 3: Definition of the long wave for measuring energy absorption capability

However, the instantaneous values of the voltage, *v* and current, *i* are not regular functions of time and these instantaneous values are not practically recorded to evaluate the integrated energy. Thus the total injected energy by a pulse of 2 milliseconds considering a constant for rectangular wave is estimated as

$$Energy = 2.28.V_{pk}\, I_{pk} \qquad (2)$$

Energy absorption capability is evaluated by dividing the quantity of energy computed from the above equation with the volume of the varistor disc.

III RESULTS AND DISCUSSIONS

To compare the energy absorption capability a total of 20 arrester blocks (10 cylindrical and 10 hexagonal) was taken. Figure 4 depicts the cumulative percent failure with respect to increasing level of energy. Failure of arrester blocks in the test for energy absorption capability is usually dominated by occurrences of pinhole and flashover. In a very few cases discs failed with crack or fracture alone. The failure mode and the location of damaged marks for each of the discs were tracked and pinhole accompanied by a flashover was observed to be they common mode of failure. Since the hexagonal discs were prepared by grinding the side surface of the cylindrical discs, variation in energy absorption capability could possibly be linked with the removal of the presumably contaminated surface of the cylindrical discs. But no such link can be validated from the observations of the failure patterns and their distribution.

Out of ten discs for each set of control and hexagonal discs there is no significant difference both in failure mode and the location of the mark or origin of failure. In both the cases, only one disc from each set exhibited failure solely through flash over, 5 and 4 failures by pinholes occur respectively for hexagonal and cylindrical discs.

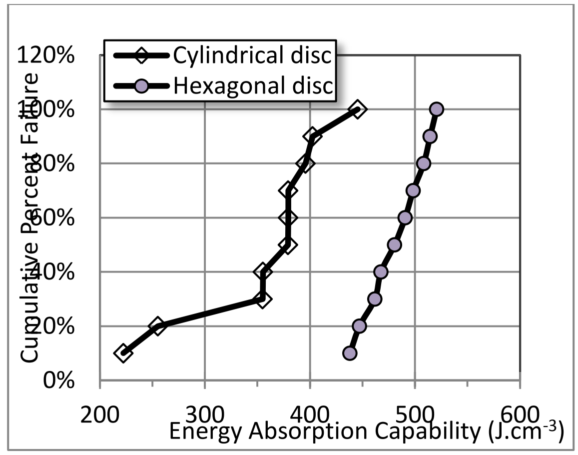

Figure.4: Variation of energy absorption capability with different geometry

The discs having hexagonal shape exhibited an average of 483 J.cm^{-3} while the discs having the cylindrical shape yielded an average of only 357 J.cm^{-3}. Thus, about 35% increase in energy absorption capability was observed for the hexagonal discs. In this test the electrical pulses applied is of 2 only millisecond duration and the arrester is considered to be heated adiabatically. But the sample of hexagonal discs having higher surface to volume ratio sustained higher capability in energy absorption. This phenomenon can be attributable to the effect of increased surface to volume ratio of arrester block. The knowledge of the influence of S/V ratio can be applied in designing the geometry of the device for improved functional reliability of electrical system.

IV CONCLUSIONS

Reliability of a surge protection system is largely dependent on the energy absorption capability. Injected energy from the stroke of transient electrical surge into the arrester body is transformed into heat and dissipated through the surface of the disc body. Higher S/V of the hexagonal disc is found to be highly conducive in heat transfer leading to enhanced life. With an increase of about 11% in S/V ratio, the average energy absorption capability for the hexagonal discs was found to improve to a level of 483 J.cm^{-3} compared to that of 357 J.cm^{-3} for the discs having the cylindrical shape which is equivalent to about 35% increase. Since there was no other variation in processing except the geometry, the significant change in energy absorption capability could be assumed as effect of increased S/V ratio of arrester block. Moreover, discs with the hexagonal shape can possibly be produced as a modular unit. By combining hexagonal modular discs side by side and end-to-end a wide range of surge arresters could be possible to be constructed. This modular concept could tremendously reduce the cost of production by avoiding setups at various points of the lengthy processing line for different capacity arrester blocks.

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