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Modelling of non-conventional instrument transformers (NCIT) by Finite Element Method FEM

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Modelling of non-conventional instrument transformers (NCIT) by FEM

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Abstract. In this paper, we have shown that the proposed non-conventional instrument transformer using magnetic shape memory (MSM) alloys can be used for current measurement in high voltage overhead transmission lines. By modelling one of the most used conductors at high voltage overhead transmission lines (400kV, 300-600A, AC) and our sensor consisting of a magnetic circuit and an MSM element, NCIT's design was optimised for these lines and it was shown that the typical values of electrical current expected in a normal working regime would trigger the MSM element. Different designs of magnetic circuits were modelled in ANSYS APDL and discussed, comparing the obtained results for several different materials for magnetic circuit.

1. Introduction

Magnetic shape memory (MSM) alloys are relatively new "smart" materials which change their shape when subjected to external magnetic fields. In paper [1] we have already proposed a novel non-conventional instrument transformer (NCIT) based on MSM alloys for measuring electrical current in HV transmission lines and in this paper, that idea is further developed in order to show its validity.

Its basic principle relies upon the proportionality of the strain produced by an MSM element which is subjected to a magnetic field produced by the current which magnitude is being measured. The output voltage V generated by the LVDT is proportional to the strain Δl, produced by the MSM element (Figure 1). This MSM strain is, in turn, proportional to the magnetic field B which is ultimately proportional to the current in the conductor, I (measurand). Our initial research showed that these sensors are not sensitive enough to be used in overhead transmission lines, but this problem can be overcome by adding a magnetic circuit, what is discussed and presented in this paper.

The results have been obtained in ANSYS APDL for AC current by creating a 2D model of the 528-Al1/69-ST1A ACSR conductor, magnetic circuit and MSM element.

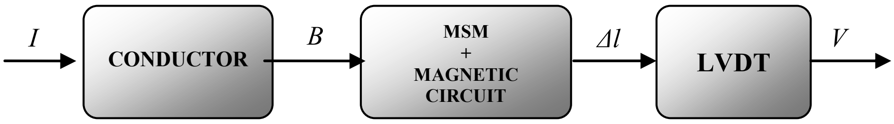

Figure 1. Schematic showing the proposed current-measurement system based on magnetic shape memory (MSM) alloys.

2. Characteristics of the modelled current carrying conductor and MSM element

2.1. Characteristics of the modelled conductor

There are many types of conductors used for overhead transmission lines. Aluminium conductor steel reinforced (ACSR) has been widely used throughout the history primarily because of its mechanical strength, already developed production capacities and reasonable cost production. A list of most common conductors used in Europe and their properties can be found in standard EN50182 [2]. ACSR is the most commonly used one at the HV level and above. For all those reasons, we modelled ACSR conductor, more specifically, 528-Al1/69-ST1A (old code MOOSE), shown at the centre of Figure 2. Furthermore, this conductor has the highest current ratings of all the conductors used in the UK. [2] Similar modelling and procedures can be easily obtained for the other types of conductors by slightly changing the source code that we have developed. The parameters used to model this conductor can be seen in Table 1.

Table 1. Parameters used to model 528-Al1/69-ST1A conductor [2]

	Number of strands	Diameter of a strand [mm]	Conductivity [S/m]	Relative magnetic permeability	Diameter of core [mm]	Total diameter [mm]	Total area [mm^2]
Steel strands	7	3.53	$5{,}21 \cdot 10^6$	100	10.6		
Aluminium strands	54	3.53	$3{,}54 \cdot 10^7$	1			
Total	61					31.8	597

During this research, it has not been found the conductor for overhead transmission lines having ampacity higher than 2,5kA [2], [3], [4]. Conductor radii are in the range 1.5cm - 1.75cm, and the current density value in normal working regime lies between 0.5 A/mm^2 and 1 A/mm^2. [3], [4]

2.2. Characteristics of the modelled MSM element

One of the most important properties of MSM alloys for this research is the value of the magnetic field which will trigger elongation of the MSM element. This threshold is characterised by the minimum value of the external stress or magnetic field required to overcome the twinning stress of a crystal and to initiate reorientation of twin variants. When an MSM element is not elongated it consists only of so-called hard variants. The relative magnetic permeability of the MSM element in this situation is μ_r=2 what was used for modelling it.

By analysing the strain-magnetic field relation of ETO Magnetic MSM crystals at different pre-stress (load) levels [5], it can be seen that the minimum value of the magnetic field triggering the MSM element (reversibly) is B=0,2T. The MSM element dimensions that can be found on the market and that are suitable for the proposed NCIT are 10mm x 3mm x 1mm.

3. Design of sensor for current measurement

Our initial research has shown that the MSM element is not sensitive enough to be used by itself for measurement of AC in high voltage overhead transmission lines in the normal working regime. That was a motivation for adding a magnetic circuit to NCIT’s design in order to collect as much as possible magnetic field around the current carrying conductor and focus it towards the MSM element. We propose two designs of magnetic circuits – a circular and a rectangular one with curved corners (Figure 2). The MSM element is placed between the circuit ends.

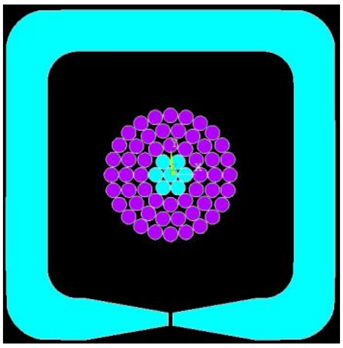

Figure 2. 2D model of the proposed NCIT - design (528-Al1/69-ST1A conductor and rectangular shaped magnetic circuit with curved corners).

In order to get higher values of magnetic flux density at the surface of the MSM element, it is desirable that the size of the air gap is as small as possible. The distance from the MSM element to the magnetic circuit in our design is 0.1mm, as the further decrease is limited by technological reasons.

Several aspects are needed to be taken in account in consideration of magnetic materials used for the circuit design such as the value of saturation flux density**,** resistivity, skin depth, availability at the market and so on. The considered materials and their characteristics can be seen in Table 2.

Table 2. Characteristics of materials considered for magnetic circuit.

Material	Resistivity [Ωm]	Relative magnetic permeability	Skin depth [mm]	Saturation flux density [T]
Hiperco 50	$40.1 \cdot 10^{-8}$	1000 – 12000	1.42 – 0.41	2.33
Radiometal 4550	$4.5 \cdot 10^{-7}$	6000 – 40000	0.62 – 0.24	1.6
Armco	$9.9 \cdot 10^{-8}$	300 – 6000	1.29 – 0.29	2.15

The skin depth is very small for the all considered materials (Table 2), thus a laminated material should be used for magnetic circuit.

Furthermore, the circuit geometry should be carefully considered as it influences its saturation point, sensitivity to the high temperatures at the surface of the current carrying conductor and, finally, possibility to trigger the MSM element. In contrast to the fixed MSM element size, there is a certain flexibility in design of the magnetic circuit in terms of its size and distance from the conductor (Table 3). The circularly shaped circuit showed almost the same sensitivity (a slightly higher) than the rectangular one.

Table 3. Triggering values of current for different designs of NCIT (r - distance from the centre of the current carrying conductor to the inner side of the magnetic circuit; w – magnetic circuit's width; t – distance from the air gap to the point where the circuit's end begins sharpening).

Material	r [mm]	w [mm]	t [mm]	I [A], 50 Hz
Hiperco 50	30	10	20	300
Hiperco 50	50	10	20	400
Radiometal 4550	30	10	20	250
Radiometal 4550	50	10	20	400
Armco	30	10	20	550
Armco	20	10	10	420

The conductor considered in this paper, 528-Al1/69-ST1A, carries 300-600A in the normal working regime. Figure 3 shows magnetic flux density in the air gap along the 3mm side of MSM element for Hiperco 50 and Armco when current is 300A (distance from the surface of MSM element is 0.05mm). The circuit geometry is the same for both materials (r=30mm, w=10mm, t=20mm).

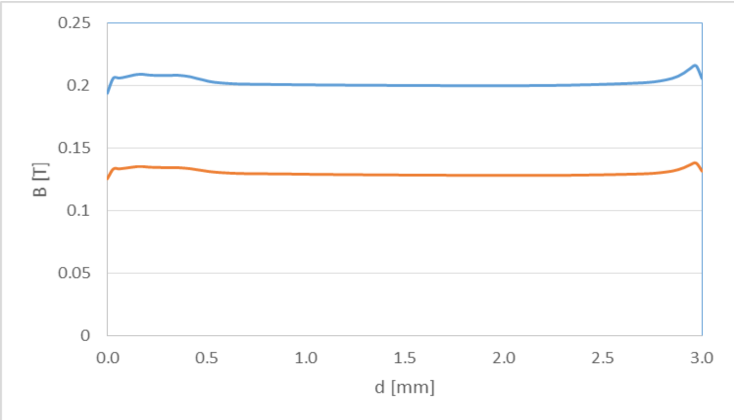

Figure 3. Magnetic flux density in the air gap along the side of MSM element for Hiperco 50 (top curve) and Armco (bottom curve). (I=300A, r=30mm, w=10mm, t=20mm).

The obtained results show that Armco is not the material recommended for this application as it cannot trigger the MSM element even if it is placed very near to the conductor. However, the NCIT using Hiperco 50 or Radiometal 4550 material for the magnetic circuit, can be triggered for the used geometry. It should mention that Radiometal 4550, although more sensible, also saturates quicker than Hiperco 50 (Table 2).

All designs and modelling in this paper were made for twin type I MSM elements, while less studied type II twin crystals can be very promising for sensor applications and offer even higher flexibility in design of the proposed NCIT if their problem with twin microstructure instability is solved in the future.

4. Conclusion

Incompatibility of conventional measurement transformers with modern equipment is one of the main reasons for searching novel current-sensing and measurement solutions based on different alternative principles.

In this paper, we have proved the validity of the proposed sensor in the paper [1] and its possible use in overhead transmission lines by modelling it in ANSYS APDL. By modelling 528-Al1/69-ST1A ACSR conductor, one of the most used conductors at high voltage overhead transmission lines, and our sensor consisting of the magnetic circuit and an MSM element, NCIT's design was optimised for these lines and it was shown that the typical values of electrical current expected in a normal working regime would trigger the MSM element. Various designs of magnetic circuits were modelled and discussed, comparing the obtained results of several different materials for magnetic circuit.

This paper provides an insight into design of a new sensor for measuring electrical current using MSM material. Though, before the viable prototype can be designed, it is still needed to do some modelling and testing what will be done in our future work.

5. References

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