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The difference among three reference standards used in the performance evaluation of wire rope EMT instrument

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Abstract

A reference standard for a unit of measurement is an artifact that embodies the quantity of interest in a way that ties its value to the reference base**.** The selection of an appropriate reference standard is a crucial point in the performance evaluation of wire rope electromagnetic testing (EMT) instrument. In this paper, a 3-D finite element model (FEM) has been developed to study three reference standards. The effects of the magnetizing ampere-turn, the loss of metallic cross-sectional area on the main magnetic flux and the structure have been addressed. Comparison analyses have been made of the simulation results of the three reference standards.

Keywords: Finite element method; Nondestructive testing; Reference standard

1. Introduce

Wire rope EMT instrument is an important instrument used in wire rope safety inspection, and its' testing precision effects on the result of wire rope condition evaluation significantly. In ASTM E 1571, a summary contend is presented to rule the wire rope EMT instrument, in the item 10.3, the rod bundle reference standard is introduced to evaluate the performance on measuring the loss of metallic cross-sectional area [1]. In practice, a standard composed of a pipe and a bundle of rods is used; however, the wire rope is a special component with complex helix structure, and there are great differences between the reference standard and the wire rope; therefore, pipe standard is just a cursory substitute, and may cause evaluation error. It is significant to reveal the difference between the wire rope and its substitutes so as to choose reference standard in reason. Large amount of references focus on the pipe EMT and wire rope EMT [2-5], but few papers are found to concentrate on the difference of magnetic performance between the wire rope and it reference standards.

In this paper, three standards have been chosen to research on their difference in magnetic character. The FEM, the most effective method to study on EMT question related to more important detail inner material, was applied to bring enough data.

Our research aims at selecting an appropriate reference standard for Wire rope EMT instrument. The approach is to investigate the magnetic character difference of three reference standards: a pipe with rod bundle, a strand and a pipe. Utilizing finite element model (FEM), numerical simulations have been conducted to investigate the difference among three reference standards studies are also conducted to investigate the effects of the magnetizing ampere-turn and the loss of metallic cross-sectional area on the main magnetic flux. Comparison analyses have been made of the simulation results.

2. The principle of EMT on the loss of metallic cross-sectional area

The test principle of the loss of metallic cross-sectional area of wire rope electromagnetic is shown in Fig.1. The exciter coil produces enough magnetizing energy to magnetize the wire rope,

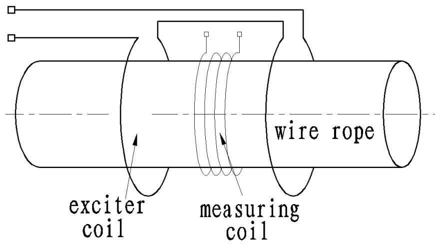


Fig. 1 Principle of wire rope EMT

then, the main magnetic flux, which passes through the cross section of wire rope, will be changed significantly when flaw lies in the wire rope, the measuring coil detect this change, finally, the change is converted into a reason result of the loss of cross-sectional area.

The EMT can be simplified as a magnetic resistant model as shown in Fig.2, where R_s is the

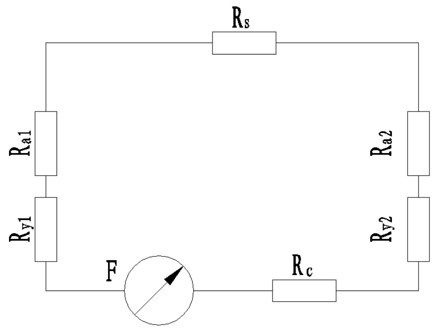


Fig. 2 Equivalent magnetic circuit of EMT of wire rope

magnetic resistant of wire rope, R_{a1} and R_{a2} is the magnetic resistant of air between the yoke and the wire rope, R_{y1} and R_{y2} is the magnetic resistant of the yoke, R_c is the inner magnetic resistant of the exciter coil, F is the magneto-motive forces of EMT system. F can be expressed as:

$$F = \Phi \cdot (R_{y1} + R_{y2} + R_{a1} + R_{a2} + R_c + R_s) \tag{1}$$

where φ is the magnetic flux through the main magnetic circuit.

Equation (1) leads to:

$$\Phi = \frac{F}{R_{y1} + R_{y2} + R_{a1} + R_{a2} + R_c + R_s} \tag{2}$$

Equation (2) shows that φ is determined by R_{y1}, R_{y2}, R_{a1}, R_{a2}, R_c and R_s, and it has a linear relationship with R_s when R_{y1}, R_{y2}, R_{a1}, R_{a2} and R_c are regarded as immobility parameter ; According to Fundamental theory of Circuit, the magnetic resistance is inversely proportional to the cross-sectional areas. Therefore, there is a linear relationship between the main magnetic flux and the cross-sectional area of wire rope. In really world, the parameters above are variable and the geometries of the cross-section of wire rope have significant effects on the main magnetic flux and the performance evaluation of EMT instrument.

3. Calculation and analysis

In order to analysis the magnetic difference among the three reference standards, a 3-D FEM has been developed as shown in Fig.3. The scale of figure adjusted to make the structure more clear. Exciter coil was adopted to provide enough magnetic energy to magnetize the reference

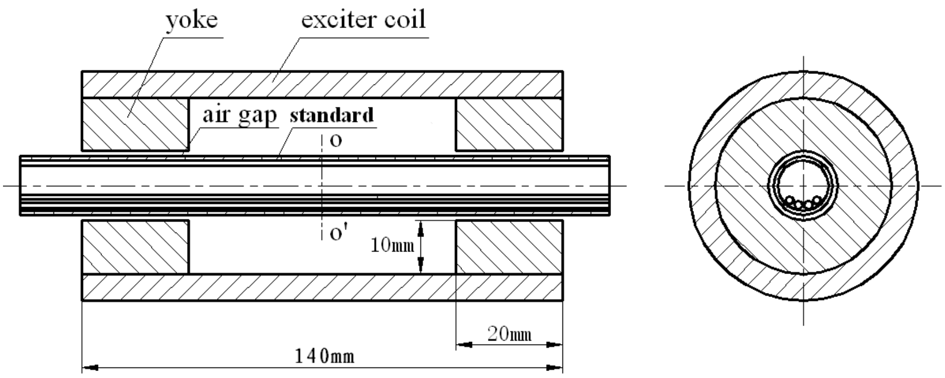


Fig. 3. Finite element model of EMT of standard

standards. In order to enhance magnetizing efficiency, a pair of cylinder yokes was set between the exciter coil and the reference standard, the reference standard was placed inner the yoke. The air gap between the yoke and the surface of reference standard is 1mm; the length of exciter coil is 140 mm.

The element type used in this model is solid117. Sweep mode and intelligent mode are used to mesh the model according to the difference of components; a typical 3-D meshing in Fig. 4. The material of standards is nonlinear, their B-H curve is shown in Fig. 5, the material of yoke is linear, and its relative magnetic permeability of material is 1000. The relative magnetic permeability of exciter coil material is 1. The relative magnetic permeability of other air space is 1. During the

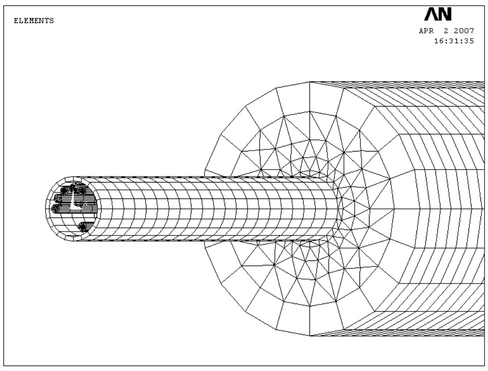


Fig. 4. Model meshing

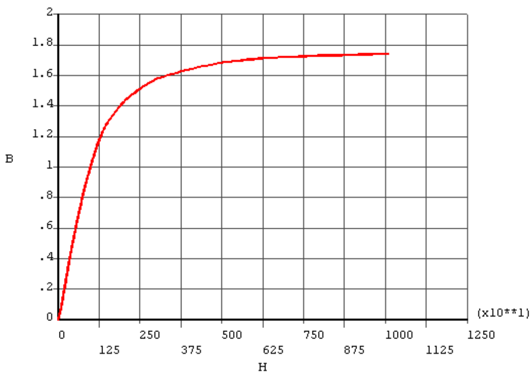


Fig. 5. B-H curve of standard

course of EMT analysis, designed ampere-turn current was imposed on the exciter coil; then, results were obtained through a designed program; the axis component of magnetic strength are mapped onto a series of path. The middle cross-section (shows in fig. 1 in o-o') was partitioned into 28800 subfields, the magnetic strength of every subfield are abstracted to form the magnetic condition of middle cross section. At last, the total magnetic flux of 'o-o' was calculated by MATLAB program and subsequently data analysis is also done using MATLAB program.

3.1 Difference when imposing the same series of ampere-turns.

Three standards are chosen to analysis the difference between wire rope and its substitutes. The strand is similar with the wire rope in structure, therefore can present some common character of helix structure; furthermore, analysis with strand can reduce calculation because wire rope can result in large amount of calculation that can be beyond the competence of ANSYS. The reason why Pipe is chosen is that solid structure may be much closer to the wire rope therefore may be much fitter as a substitute. Figure 6 is the cross section of three reference standards, for the first reference standard, the outer diameter of pipe is 15 mm, the thickness of pipe is 3.35 mm, the

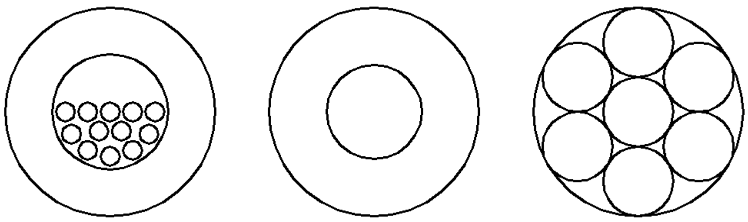


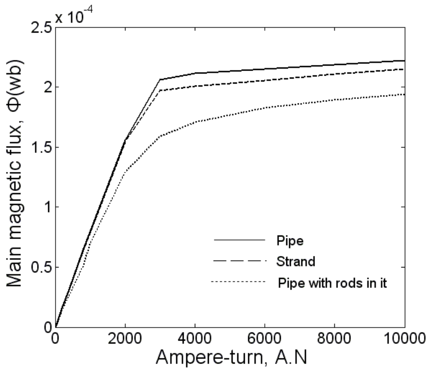
Fig. 6. Cross section of standards

diameter of rod is 1.34 mm, and the number of rods is 12, and the cross-sectional area of rod is close to 1% of total cross-sectional area of standard. For the second standard, the diameter of pipe is 15 mm, and its thickness is 4.1 mm. For the third standard, the outer diameter of strand is 15 mm, the diameter of wire is 5 mm, and the number of wire is 7. The area of three standards shows in table 1.

Table 1:

	Diameter	Cross-sectional area	error
Pipe with rods	15	140.4	0.2%
Strand	15	140.1	0%
Pipe	15	139.5	0.4%

200, 400, 800, 1000, 2000, 3000, 4000, 6000, 8000 and 10000 ampere-turn are imposed on the three simulation models in sequence. Curves between the main magnetic flux and the ampere-turn show in figure 7. Figure 7 shows that the curves are similar with the B-H curve of



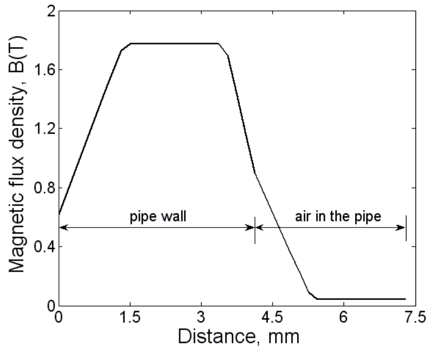


Fig. 7. Relationship between the main magnetic flux and the ampere-turn EMT of wire rope

Fig. 8. Magnetic strength in the pipe wall

steel material shows in fig. 5. The main magnetic flux of pipe is larger than that of strand, and the main magnetic flux of strand is larger than that of pipe with rods. The reason that results in this phenomenon is that the magnetic field in the research area is not so uniform; figure 8 is the curve between the axis component of magnetic strength and the position along the outer surface to the inner surface of the pipe. Figure 8 shows that there are a start area, a steady area and an end area, in the start area, the magnetic field increase from a low level to a high level; in the steady area, the magnetic field is uniform; in the end area, the magnetic field decrease from a high level to a low level. This phenomena lie in every single body, so different distribution of metal can result from different total main magnetic flux; therefore, the metal is more compacter, the main magnetic flux is larger.

3.2. Difference when making the same loss of metallic cross-sectional area

Calculation is carried out to analysis the sensitivity difference of the three standards on the loss of metallic cross-sectional area. Two methods are applied to create the loss of cross-sectional area; for the pipe and the strand, the method is cutting out some surface metal in sequence to simulate the wear; for the pipe with rods bundle, the method is moving out some rods in sequence to simulate the vary of cross-sectional area. The ampere-turn imposed on the model is 6000, the loss used to analysis the difference in sensibility in loss of metallic cross-sectional area is 0%, 2%, 4%, 6%, 8%, 10%, 12%. Figure 9 shows the sequence of loss of cross-sectional area, the area

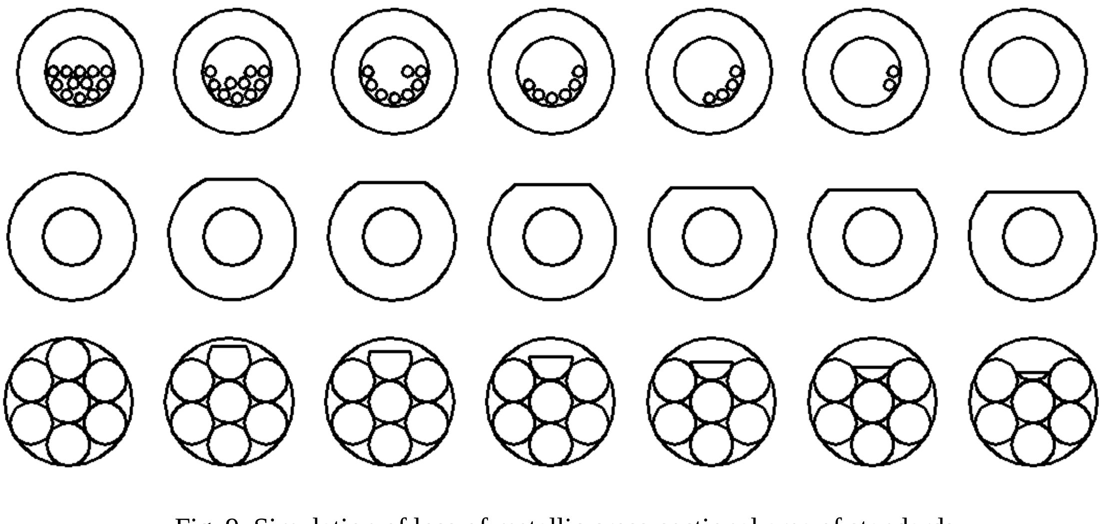


Fig. 9. Simulation of loss of metallic cross-sectional area of standards

error rate of every change is under 0.1%. Curves between the main magnetic flux and the loss of metallic cross-sectional area show in figure 10. Figure 10 shows that the main magnetic flux is well linear with the loss of cross-sectional area that means that three standards have similar

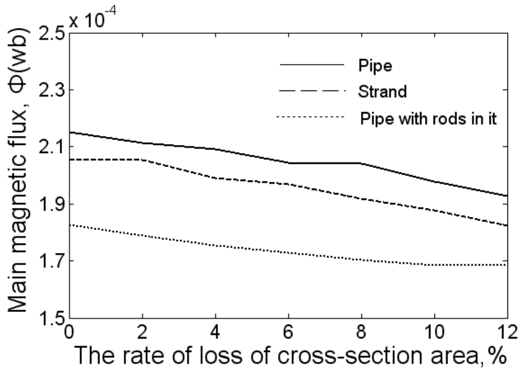


Fig. 10. Curves between the main magnetic flux and the rate of loss of cross-sectional area

sensitivity to the loss of metallic cross-sectional area; therefore, an instrument can make similar evaluating result by different standard. But the working point of three standard are dissimilar, the highest is the pipe, and then is the strand; the lowest is the pipe with rods bundle.

4. Discussion and conclusion

Wire rope is a special component, a common wire rope is compose of 3 mainly units, the core, the king wire and the strand. In order to produce a wire rope, firstly Wire screw around the king wire and make a strand, during this period, the wire is 1 time helix cylinder; secondly, strands screw around the core and make a rope, during this period, the wire is 2 time helix cylinder. Therefore, the wires are inter twisted together, and it is very difficult to make exact loss of cross-section, and the substitute must be use when evaluating a wire rope EMT instrument.

ASTM E 1571 calls for rod bundle reference standard as a substitute of wire rope to evaluate the inspecting performance on loss of metallic cross-sectional area. In practice, a pipe with rod bundle in it may be more convenient because it can uniform the outer diameter of reference standard and avoid some influence result from the position change of rods.

It is very difficult for EMT instrument custom to keep uniform distribution of rod; therefore, different evaluation results can be made by different evaluators. Pipe reference standard is prone to uniform; the wear is easier to make using standardization procedure.

Data shows that pipe standard and pipe standard with rod bundle are similar with strand standard which is a representation of wire rope in magnetic performance. When imposing current density on the standards in sequence, the curve of main magnetic flux are similar, but the working points are dissimilar, the highest is the pipe, and the follower is the strand, and the lowest is the pipe with rod bundle in it. When change the cross-sectional area of standard in sequence, the main magnetic flux of three standards are similar in sensitivity in the loss of metallic cross-sectional area, but the working points are dissimilar, the highest is the pipe, and the follower is the strand, and the lowest is the pipe with rod bundle in it.

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