APPLICATION NOTE

Measuring the Magnetic Permeabilty μ_r of Metals with the MS2K Sensor

Background

an issue when measuring the permeability μ_r of metals using the alternating field of the MS2 or MS3 meter is the effect of sample conductivity. This can give rise to an apparent negative or diamagnetic susceptibility reading. The effect is proportional to the square root of the frequency of measurement and to the shape of the specimen.

The problem can be alleviated by using a sensor with a low operating frequency. The MS2K sensor's low operating frequency of 930Hz and ability to be positioned at the point of interest makes it a good choice for the measurement of the magnetic properties of poorly conducting metals.

Method

Ideally measurements should be taken along the narrow edge of a strip of the material, and the sample materials should be in sub-millimetre granular form. (If samples are not in granular form then measurement of highly conductive materials, e.g. silver, copper, aluminium, brass (where the respective resistivity ρ is approximately 1.6, 1.7, 2.7 and 6.5 micro ohm centimetres) is not possible. Bulk measurements of magnetic susceptibility κ are however possible for the poorer conductors, e.g. stainless steels: AISI 304, 321, 347, 316 where respective resistivity ρ is approximatey 72, 73, 73 and 78 micro ohm centimetres.

Here the resistivity is relatively constant for the different formulations but the permeability can vary considerably between a value of μ_r = 1.0 and μ_r = 1.01, κ = 0 to κ =10,000 where μ_r = 1 + κ.)

The resistivity and relative permeability of the specimen will also determine the depth of penetration of the sensor's magnetic field where:

Depth $S = \sqrt{2\rho/\varpi\mu}$

and is defined as that depth at which the flux diminishes by a factor of 1/e (0.37). From the examples given below it is apparent that at a

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frequency of 1kHz the skin depth for stainless steel is compatible with measurements performed using the MS2K sensor:

Cu, Ag	S = approx 2 mm
Fe	S = approx 0.2mm
Stainless steel	S = approx 14mm

By comparison the high value of μ_r = 500 for Fe and the low values of ρ = 1.69 and 1.63 respectively for Cu and Ag result in a shallow skin depth S which is incompatible with this type of measurement.

Experiment

An experiment was performed to demonstrate the method. Three specimens of stainless steel were measured on the x1.0 range of the MS2 meter using the MS2K sensor. In each case the specimen was placed parallel to the sensor surface. The specimens were:

(a) 50 x 50 x 0.5mm sheet AI SI 316 (A4)

(b) 4mm diameter rod AI SI 304 (A2)

(c) 10mm diameter rod AI SI 316 (A4)

Four measurements were performed in sequence:

1. As received.
2. Following heating to circa 1000°C for one minute and air cooling.
3. Following hammering for one minute.
4. Following bending in two planes beyond elastic limit.

An additional measurement of magnetic susceptibility was performed using a crude (±20%) force balance method on specimen (b). Results are shown in brackets.

The results were as as shown below. The results confirm that the manipulated value for that the manipulated value for the magnetic susceptibility of stainless steel can be measured using the MS2 meter and MS2K sensor.

Experiment	Specimen A	Specimen B	Specimen C
(1)	+160	3,800 (60g)	635
(2)	22	112	128
(3)	44	250	ND
(4)	77	325 (5g)	ND