Inspection of electroplated materials-performance comparison with planar meander and mesh type magnetic sensor

International Journal of Applied Electromagnetics and Mechanics 15 (2001/2002) 323–329
IOS Press

Inspection of electroplated materials – performance comparison with planar meander and mesh type magnetic sensor

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Abstract. This paper has investigated the possibility of applying nondestructive evaluation technique for finding the defects in electroplated materials. Planar meander and mesh type magnetic sensors have been considered and their relative performance have been compared based on a single criterion that the effective area of the material surface covered by each type of sensor is same.

1. Introduction

Nondestructive evaluation techniques are able to detect the presence of cracks, discontinuities, mechanical fatigue and so many other problems without material damage resulting the application of this techniques has increased considerably in recent times. It has been demonstrated that the mechanical stress has the ability to change the electrical properties [1], resulting the change of electrical property such as electrical conductivity can be used as an index of mechanical fatigue. The planar type meander coils has already been used for the evaluation of near-surface material properties [2,3]. The application of a planar type meander coils for the inspection of defects in the printed circuit board has already been investigated in our laboratory [4]. The use of planar type meander coils has been extended for the estimation of near-surface material properties [5]. This paper has considered the application of both planar meander and mesh type magnetic sensors for the inspection of defects in electroplated materials. Their relative performance have been compared based on a single criterion that the effective area of the material surface covered by each type of sensor is same.

2. Inspection of electroplated materials

A practical problem arises in a gas-turbine blade where a conducting metal surface (TBC) is being electroplated by an non-conducting insulating layer ($Y_2O_3ZrO_2$) to prevent the heat conduction. Since

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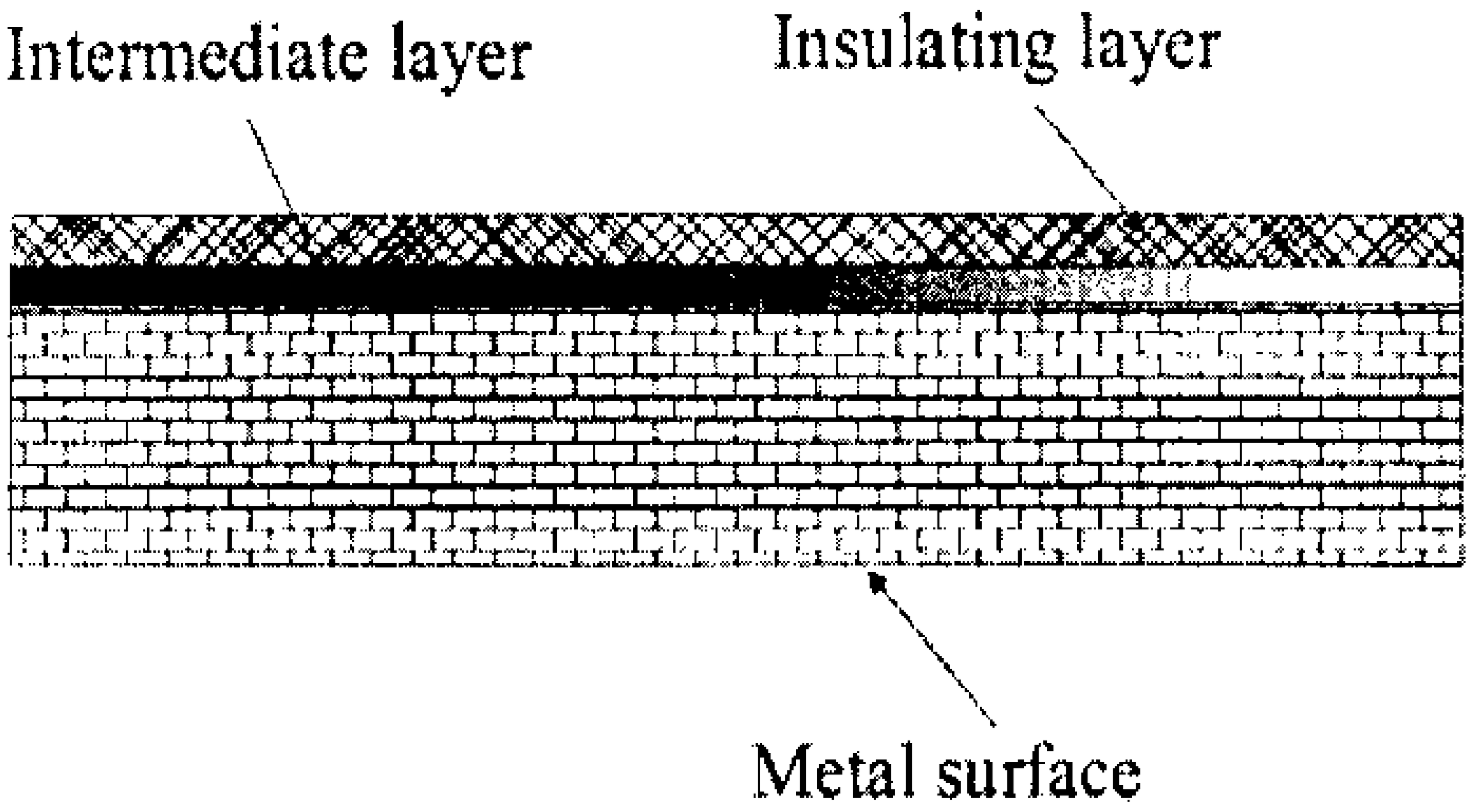

Fig. 1. Schematic of the electroplated material.

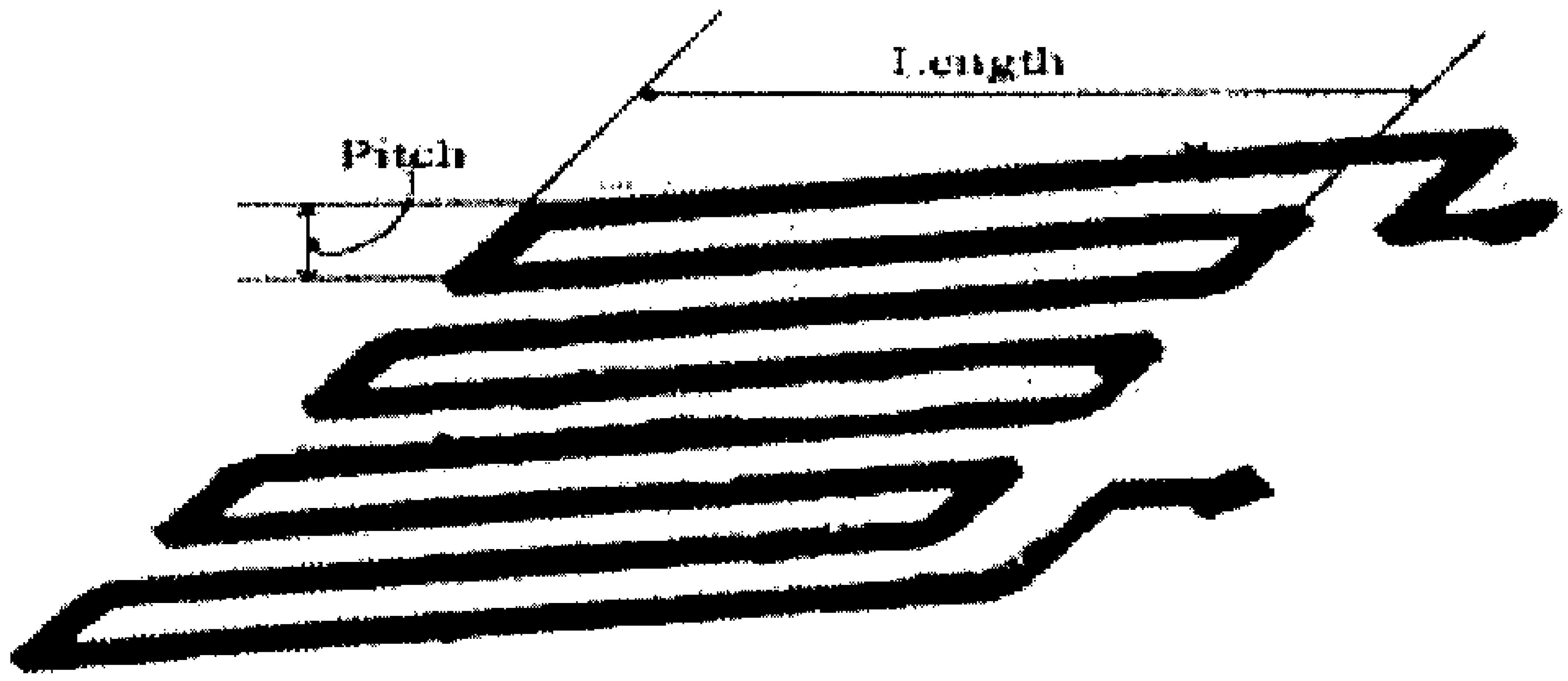

Fig. 2. Configuration of meander type sensor.

it is difficult to electroplate the above, a very thin intermediate bond coating layer (NiCrAlY) having a low conductivity has been used. The intermediate layer is very important for the proper functioning of the system especially in hazardous environment and the non-uniformity in the intermediate layer can result in catastrophic failure of the system. A schematic of the system is shown in Fig. 1. It is assumed here that the uniformity of the conductivity and the thickness of the intermediate layer can dictate the quality of this kind of electroplated materials. So the purpose of this work is to investigate the possibility of estimating the conductivity and the thickness of the intermediate layer using nondestructive evaluation technique. The transfer impedance (i.e., the ratio of the sensing voltage to the exciting current) of the probe is measured by placing it on the electroplated material and is used for the estimation of the quality as well as the detection of any kind of defects.

3. Configuration of sensors and the basis of comparison

For the purpose of performance evaluation two types of probe have been considered. One is meander type, the configuration of which is shown in Fig. 2 and the other one is mesh type, the configuration of which is shown in Fig. 3.

The basis of comparison of their performance is that the surface area covered by both sensors is same. The surface area, S_{meander}, covered by the meander type of probe is given by, $S_{\mathrm{meander}} = \mathrm{Length} \cdot \mathrm{Pitch} \cdot \mathrm{M}_1$ where M_1 is the number of pitches of the coil. The surface area, S_{mesh}, covered

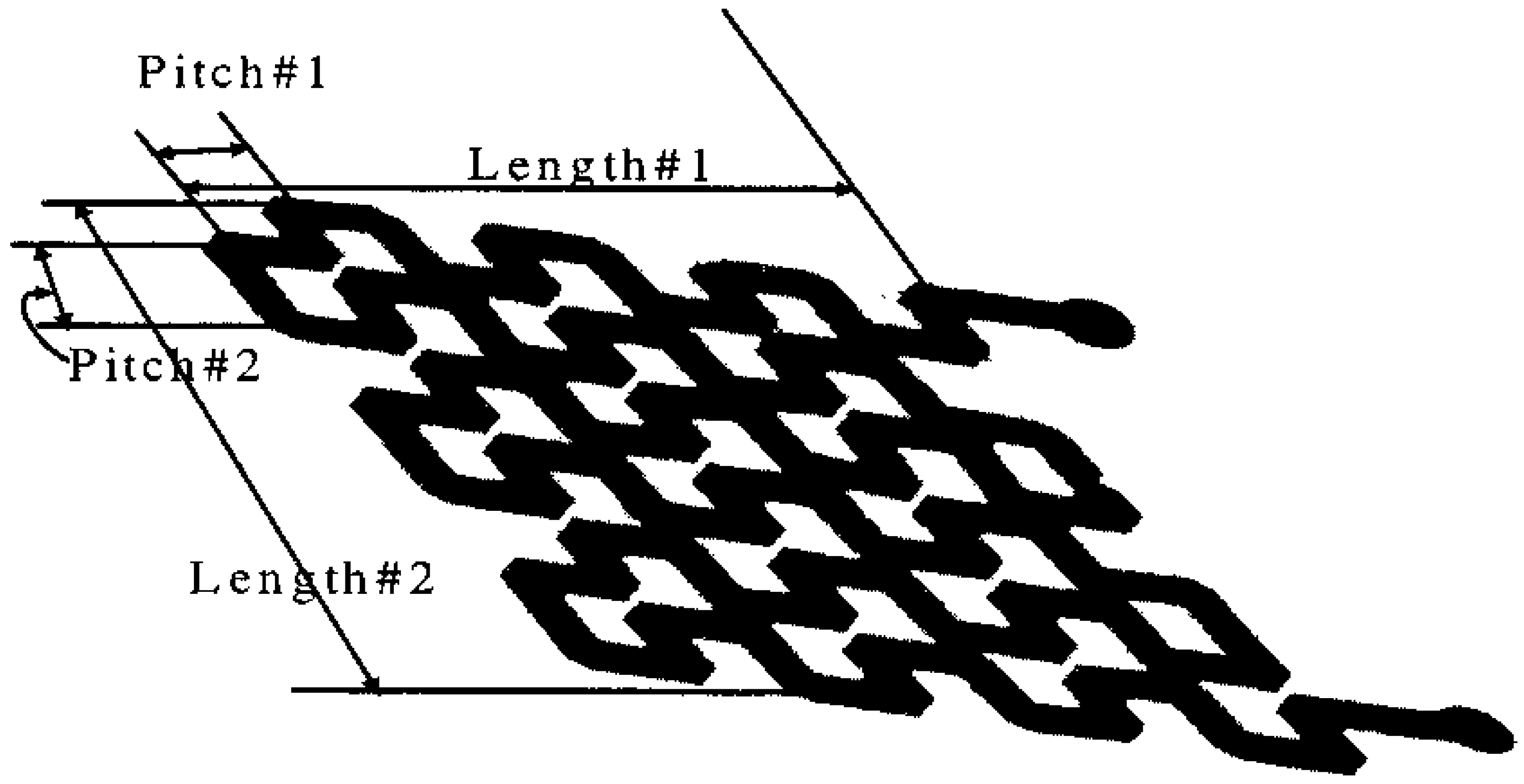

Fig. 3. Configuration of mesh type sensor.

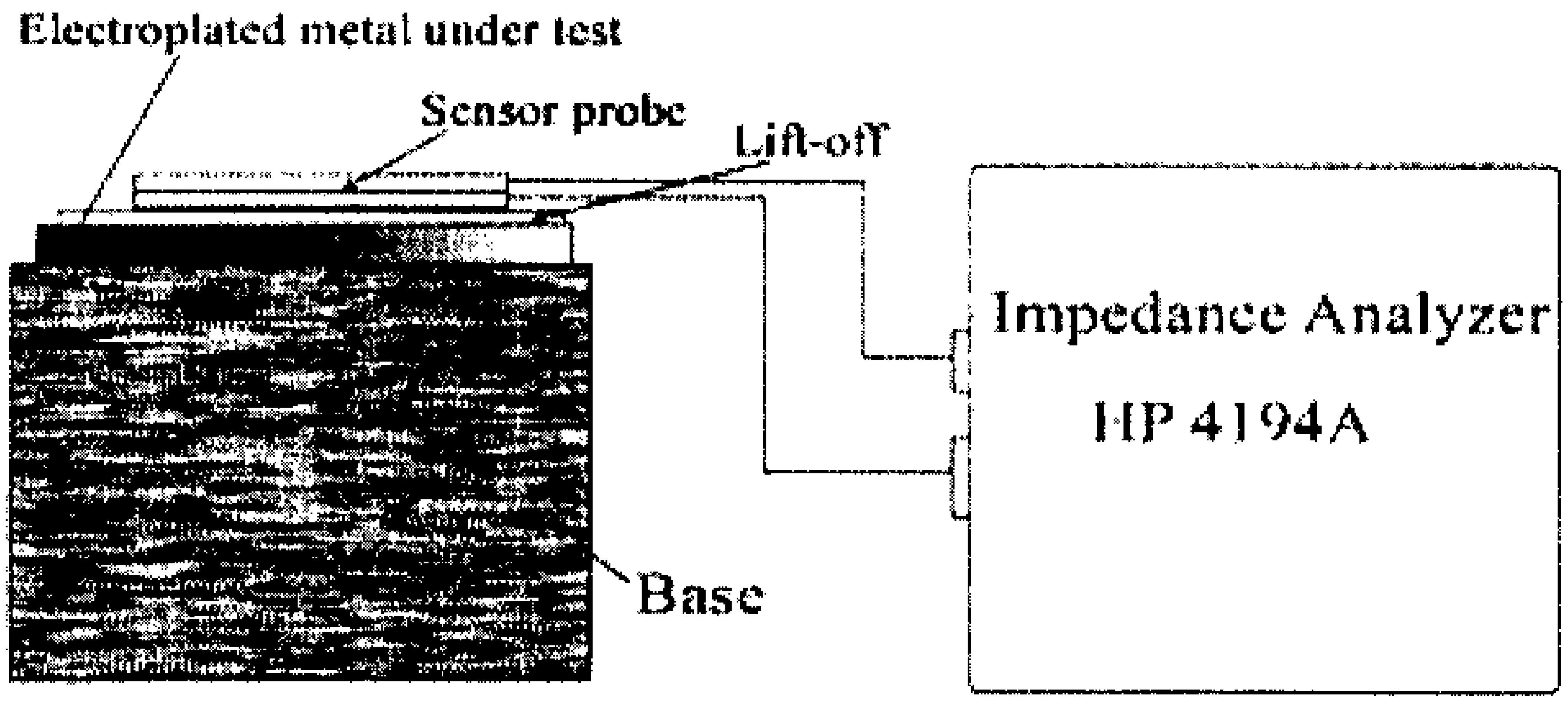

Fig. 4. Experimental set-up.

by mesh type probe is $S_{\text{mesh}} = (\text{Pitch}\#1 \cdot \text{N}_2) \cdot (\text{Pitch}\#2 \cdot \text{M}_2)$, where M_2 and N_2 are the number of pitches of the coil along the two axes respectively. Usually M_1, M_2 and N_2 are taken as integer. A square mesh coil configuration has been assumed which means Pitch#1 and Pitch#2 are same. So we have the following condition $\text{Length} \cdot \text{Pitch} \cdot \text{M}_1 = (\text{Pitch}\#1 \cdot \text{N}_2) \cdot (\text{Pitch}\#2 \cdot \text{M}_2)$. Simplifying, we have $\text{M}_1 \cdot \text{Pitch} = \text{M}_2 \cdot \text{Pitch}\#2$ and $\text{Length} = \text{N}_2 \cdot \text{Pitch}\#1$.

4. Analytical model and results

By placing the probe on the electroplated material as shown in the experimental set-up in Fig. 4, the impedance of the probe is measured. The impedance is used for the evaluation of the material properties. The impedance of the probe is a complex function of many parameters and is difficult to express in a simple form. In order to study the characteristics of impedance as a variation of important parameters, an analytical model has been developed for the calculation of the impedance of the probe. A two-dimensional model for the meander coil for one pitch is shown in Fig. 5. The detail of the modeling for the meander type probe has been described in [5] and is avoided here. For the mesh type probe two 2-dimensional model along two mutual perpendicular axis has been assumed and total impedance is obtained by superposition of two.

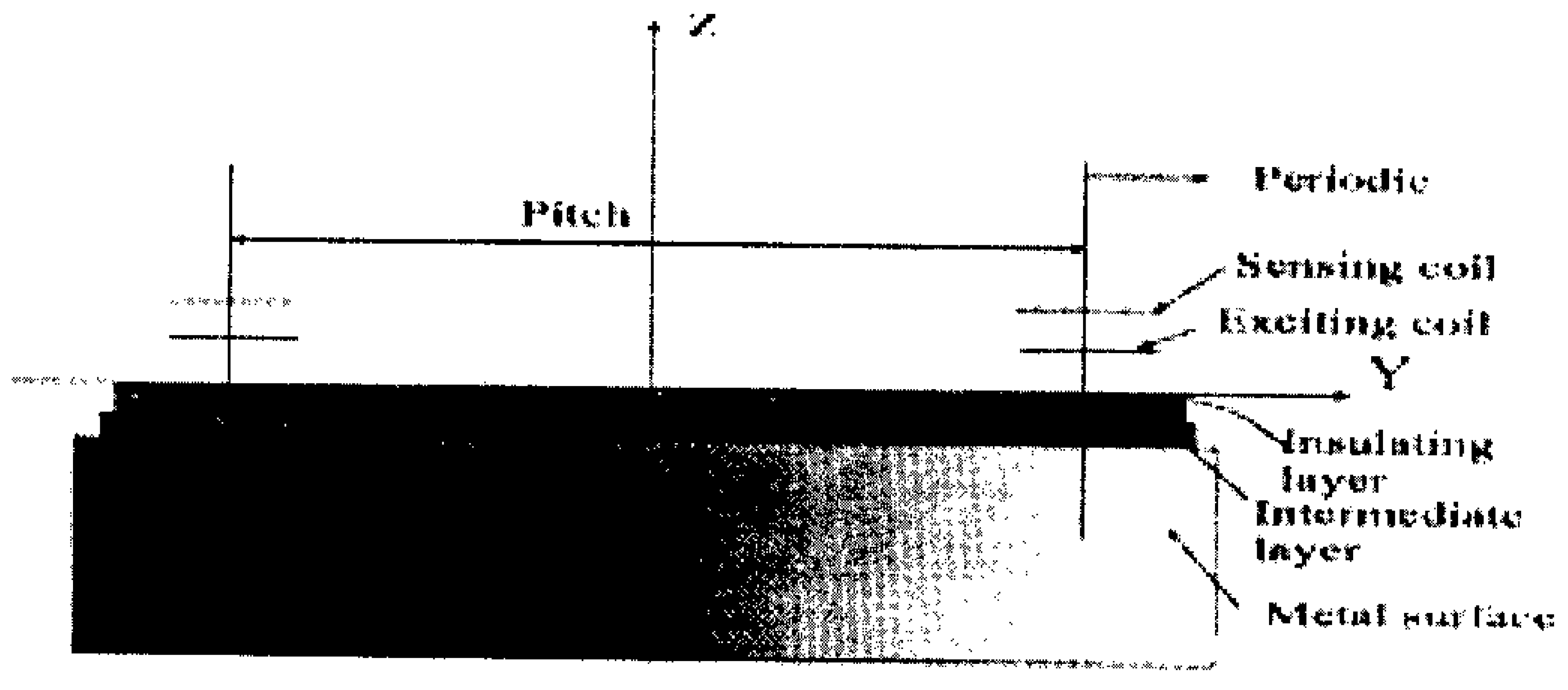

Fig. 5. 2-dimensional model.

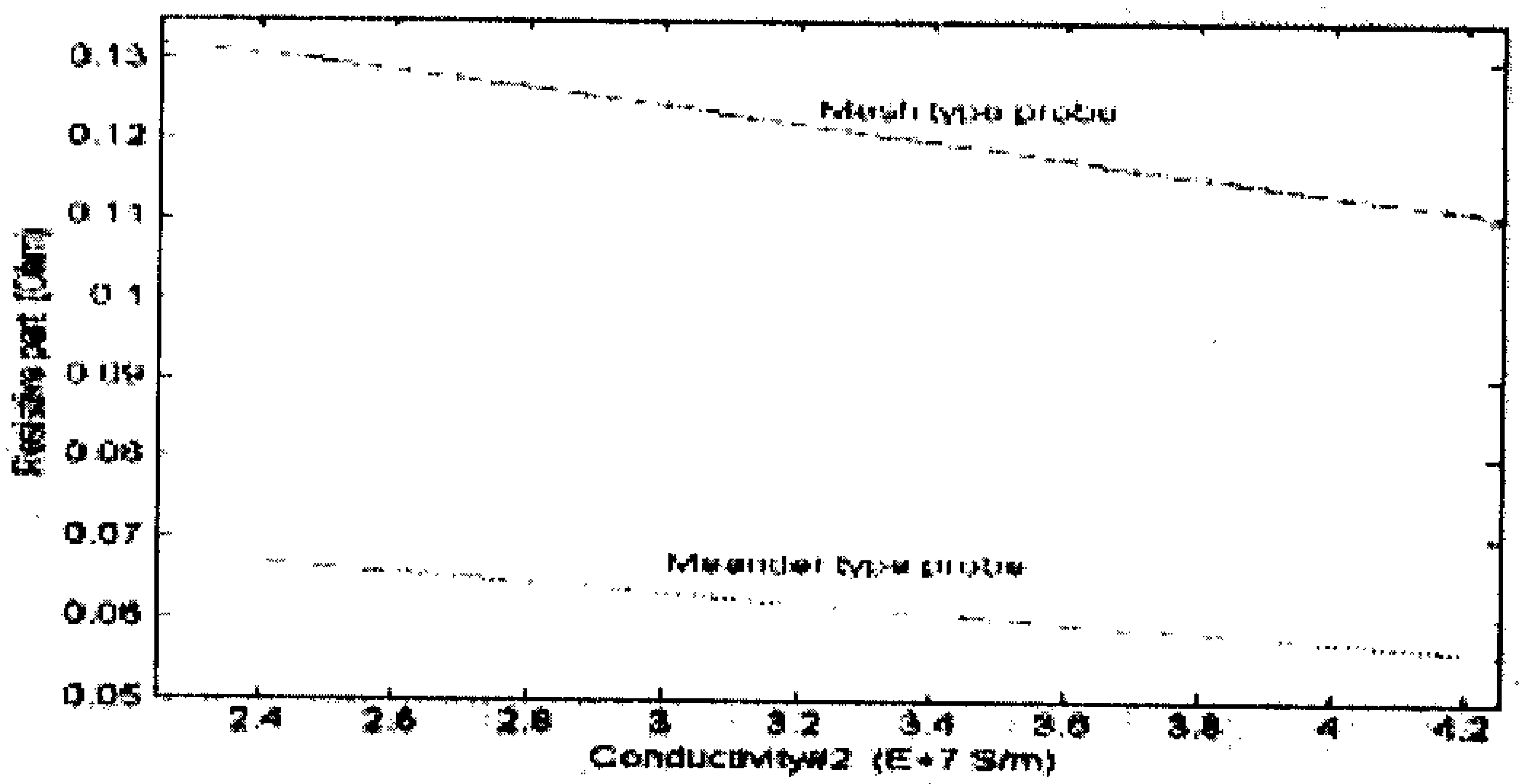

Fig. 6. Variation of resistive part with conductivity of the intermediate layer.

Out of so many results obtained only two characteristics are shown here. Figure 6 shows the variation of the resistive part of the meander and mesh type probe with the conductivity of the intermediate layer. It is seen that there is an appreciable amount of change of the resistive part with the conductivity. The conductivities along both the axis (i.e., X and Y-axis) are same. The change in the resistance for the mesh type probe is higher than that of meander type probe.

Figure 7 shows the variation of the resistive part with the conductivity along the X-axis for the mesh type probe. The resistive part for the meander type probe will not show any change as it was not possible to include that in the model. This situation will arise when there is a crack along the X- axis in which case the meander coil will not be able to detect it.

5. Experimental set-up and quality estimation

The experimental set-up is shown in Fig. 4. The probe is placed on the electroplated material and the transfer impedance (i.e., the ratio of the voltage of the sensing coil to the current of the exciting

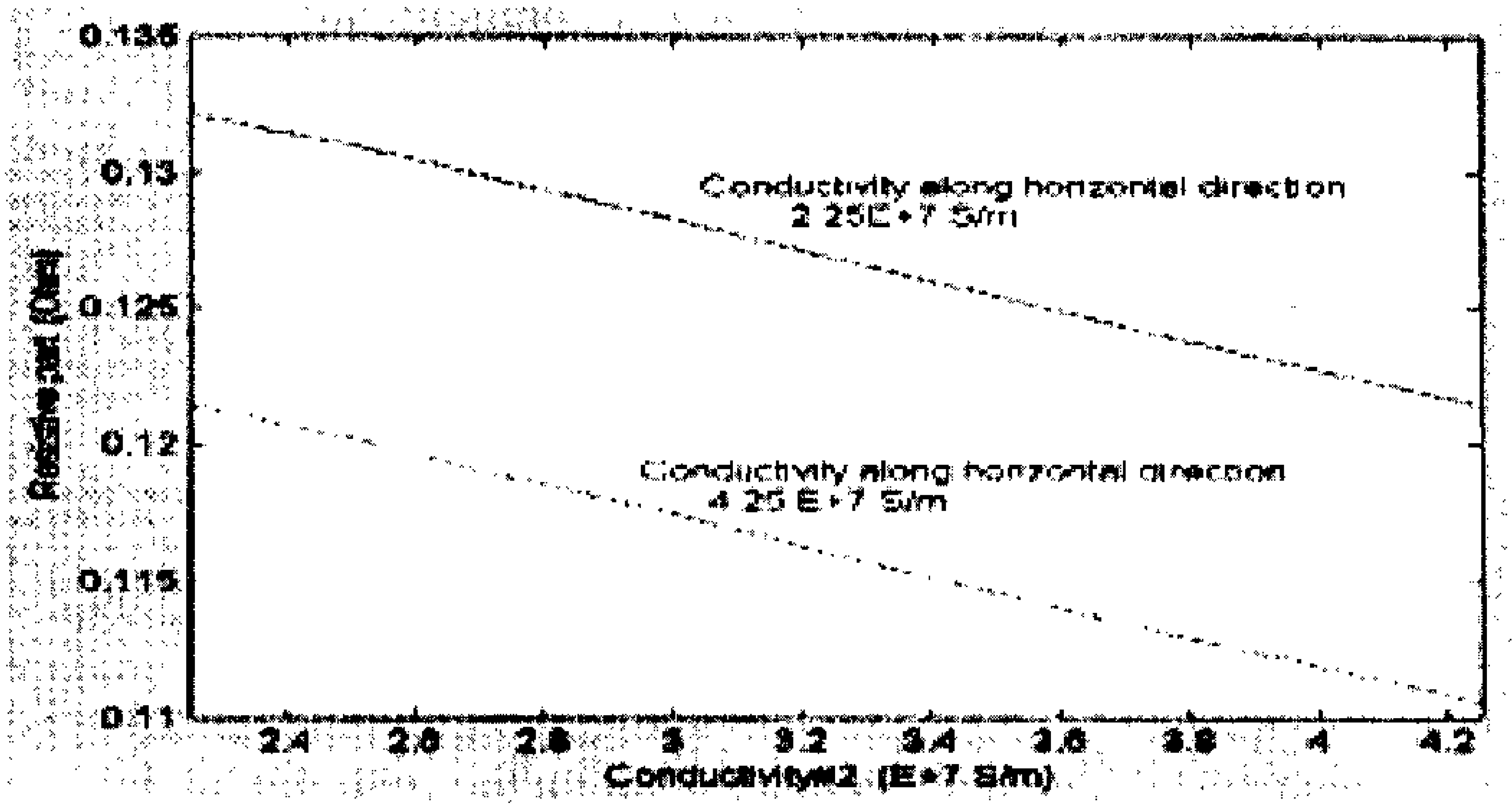

Fig. 7. Variation of resistive part with the X-axis conductivity of the intermediate layer.

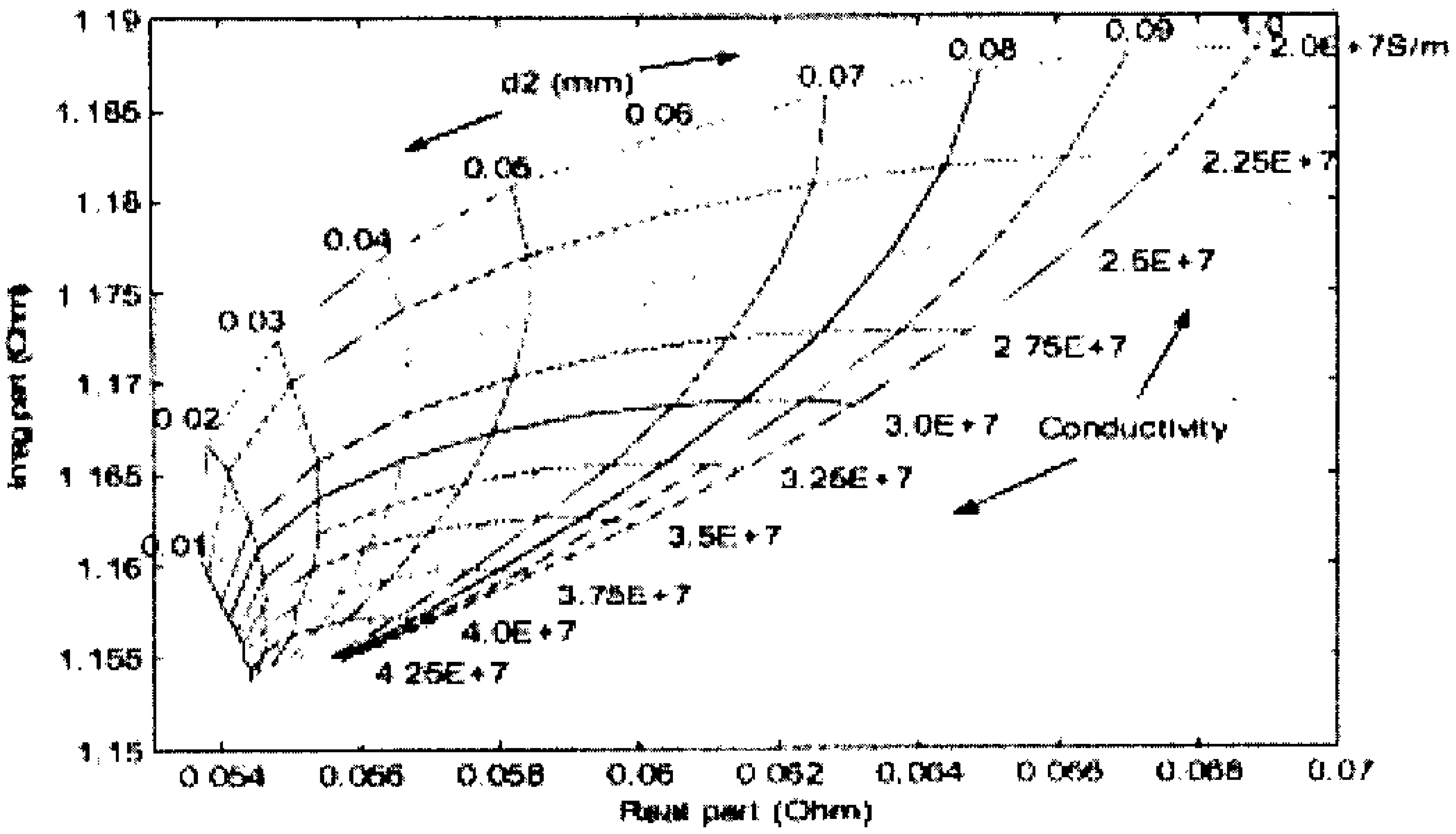

Fig. 8. A typical grid system for meander probe.

coil) is measured with the help of Hewlet Packard make impedance analyzer HP 4194 A. It is difficult to determine the conductivity and thickness of the bond coating material from the measured impedance data of the sensor in a direct way. The use of a grid system generated from the analytical model has made it possible. A typical grid system corresponding to the operating frequency of 1 MHz for the meander type of probe is shown in Fig. 8 and that of mesh type of probe is shown in Fig. 9 respectively. It is seen for the same surface area covered by both the probes, the change in resistance for mesh type probe is larger than that of meander type probe. The measured data is plotted on the grid system and by interpolation technique the conductivity and the thickness of the intermediate layer is determined. The relative performance of both type of have been compared.

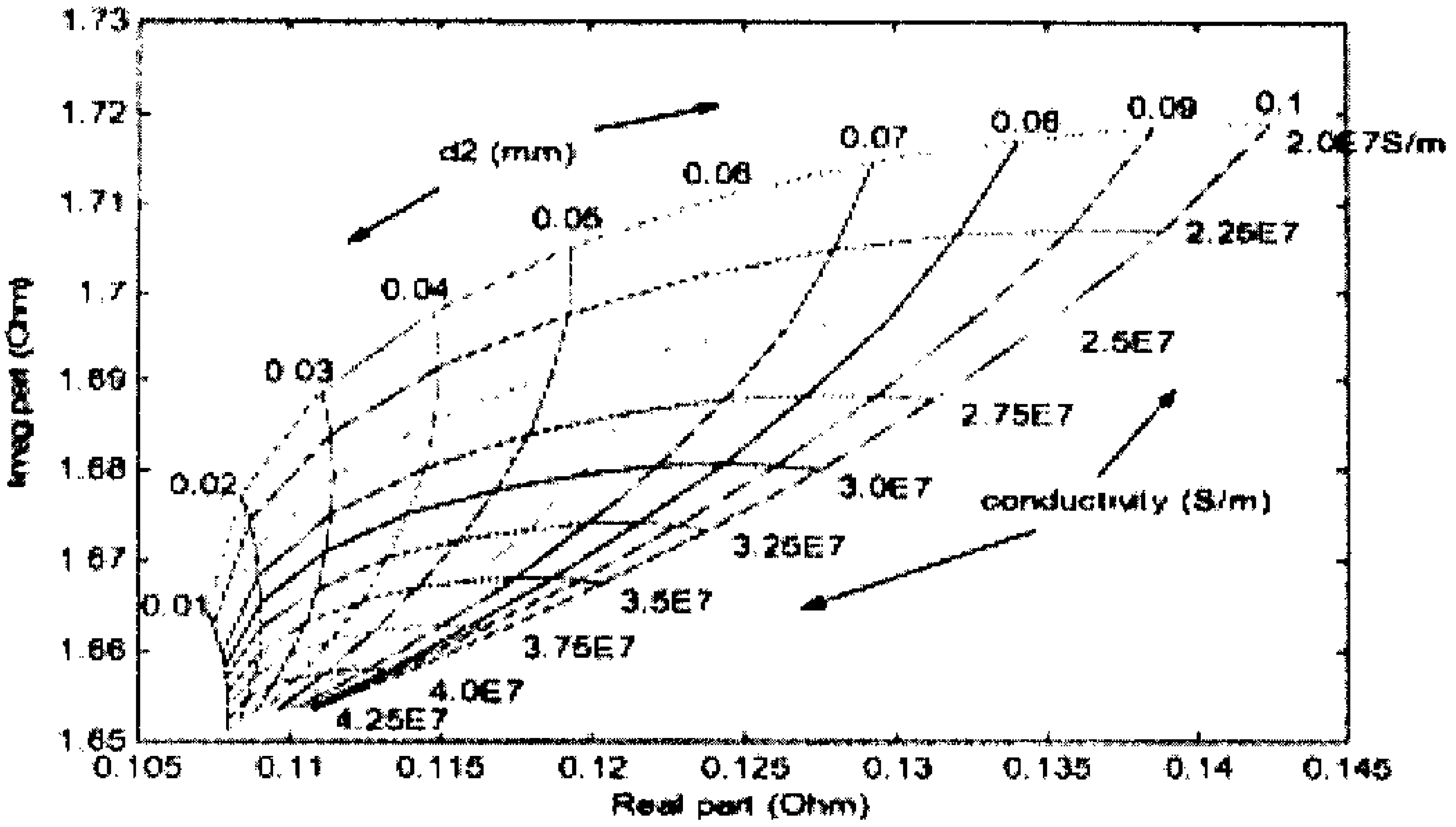

Fig. 9. A typical grid system for mesh probe.

Table 1
Results for different material

Freq	0.05 mm Tungsten		0.05 mm Molybdenum	
(kHz)	Real(Z)	Image(Z)	Real (Z)	Image(Z)
250 kHz	0.019272	0.42921	0.020935	0.42335
500 kHz	0.052162	0.84694	0.054715	0.83488

Table 2
Results for different thickness

Freq	0.02 mm Tungsten		0.04 mm Tungsten		0.05 mm Tungsten	
(kHz)	Real(Z)	Image(Z)	Real (Z)	Image(Z)	Real (Z)	Image(Z)
250 kHz	0.02082	0.40293	0.018949	0.4129	0.019272	0.42921
500 kHz	0.0513	0.80926	0.05029	0.81756	0.05216	0.84694

Table 3
Performance comparison

Conductivity of Intermediate layer (S/m)	Measured by Meander probe	Measured by Mesh probe
1.82E7	1.656E7	1.6944E7
1.67E7	1.534E7	1.569E7
1.5E7	1.388E7	1.41E7

6. Experimental results

In order to verify the performance of the probes the electroplated material is simulated in the laboratory and by placing the probe on that the impedance has been measured. Table 1 shows the impedance data of the meander probe at 250 kHz and 500 kHz for a base of 5 mm copper plate and the top layer of 0.5 mm insulating layer. The intermediate layer is 0.05 mm thick tungstenand molybdenum material. Table 2 shows the impedance data of meander probe at 250 kHz and 500 kHz for a base of 5 mm copper plate and the top layer of 0.5 mm insulating layer with variable thickness of tungsten material. For the determination of the conductivity and the thickness of the intermediate layer the probes are placed on the simulated electroplated material and using the generated grid model the parameters are determined. For the purpose of comparison the conductivities of intermediate layers of different materials are measured by both types of probes. Table 3 shows a comparative values obtained from the measurement. The mesh type probe used here has got 9 pitches along both the X and Y axis. It is seen that the mesh type probe gives slightly better result than that of meander one. If an optimized mesh probe is used that will give much better performance and the fabrication is going on for that.

7. Conclusions

In this paper planer meander and mesh type of magnetic sensors have been used for the quality estimation of electroplated material and the relative performances of both type of probes have been compared with the constraint that the surface area covered by them is same. A mesh type probe available in the laboratory has been used and shows slightly better results than that of meander one. It is expected that an optimized designed mesh type probe will give much better results and will be able to detect any flaws having any kind of angular alignment at near surface compared to meander type of probe.

References

[1] Y. Shi and D. Jiles, Finite element analysis of the influence of a fatigue crack on magnetic properties of steel, *Journal of Applied Physics* **1** (June, 1998), 6353–6355.

[2] N. Goldfine, D. Clark and T. Lovett, *Material characterization using model based meandering winding eddy current testing (MX-ET)*, EPRI Topical Workshop: NDE Applications, Charlotte, USA, Aug, 21–23, 1995.

[3] N. Goldfine and D. Clark, *Near surface materia property profiling for determination of SCC susceptibilty*, 4th EPRI Balance-of-Plant Heat Exchanger NDE Symposium, WY, June, 10–12, 1996.

[4] S. Yamada et al., Investigation of printed wiring board testing by using planar coil type ECT probe, *IEEE transc. On Magnetics* **33**(5) (Sept, 1997), 3376–3378.

[5] S. Yamada, S.C. Mukhopadhyay and M. Iwahara, *Impedance characteristics of planar meander coil for the evaluation of material properties at near-surface*, paper on technical seminar on Magnetics, Mag, 99–193, Dec, 11–12, 1999, pp. 7–12.