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DEVELOPMENT OF MICROWAVE PYRAMIDAL HORN ANTENNA BY ELECTROFORMING METHOD

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ABSTRACT

Horn antennas are the most popular microwave antennas and are used for high power handling. Development of mechanical hardware for microwave frequency ridged horn antennas demand extremely close dimensional tolerances and surface finish that must be controlled on internal dimensions and on surfaces of intricate shapes to meet the electrical requirements. Microwave pyramidal horn antenna having narrow size at waveguide transition portion with tapered ridges posses challenges in development of antenna by conventional manufacturing method. Manufacturing by milling and welding methods have limitation in realization of pyramidal horn antennas in terms of achieving dimensional tolerances and surface finishes. Electroforming is a best suitable method to develop thin walled, complex internal shaped pyramidal horn antennas. This paper describes developmental aspects of thin walled microwave frequency ridged horn antennas by electroforming method. The pyramidal horn antennas were manufactured using conventional and electro-forming methods and were subjected to electrical performance test to investigate the performance enhancement.

Keywords: *Microwave Pyramidal Horn Antenna, Electroforming, Surface Finish, VSWR, Mandrel.*

1. Introduction

The purpose of an antenna is to act as a transducer between electrical oscillations or propagated guided waves and a propagating electromagnetic wave in free space. The same antenna can be used for both receive and transmit with equal success as they obey the law of reciprocity. Due to practical or mechanical reasons, specific antennas for one or the other modes will be used but electrically they are same. [1]

Microwave antennas are used in communication, Non communication and radar systems. Microwave antennas are almost invariably of aperture type. Pyramidal microwave horn antennas are flanged in vertical and horizontal planes having tapered ridges to cover broad band frequency. [2][3]

With increasing trend towards ever smaller, complex electronic circuitry and equipment, it follows that precision parts and components used in electronic systems need to be produced with complex shapes and ever tighter tolerances. The complex internal profile, shapes of wave-guides and antennas poses challenges to mechanical engineers in realization of the hardware. The electroforming method is the suitable candidate for development of such complicated components in research and development activity where the quantity of production is very small.

Using the voltaic cell as the current source Carlisle and Nicholas described the first copper deposits obtained by electrolysis of an aqueous solution during eighteenth century. Professor B.S. Jacobi of the academy of sciences, St. Peterburg, Russia is credited with discovering electroforming during his investigations on galvanic cells early in 1837. Electroforming method became more versatile in producing minute components and complex features that cannot be achieved by other manufacturing methods. The recent advancement in application of electroforming technology is to manufacture minute components and features such as encoders, discs, foils, orifice plates, optical masks and other fine and intricate components. Electroforming method has been adopted in development of microwave pyramidal horn antenna having critical and intricate internal shape. [4][5]

Thin walled ridged horn antenna was developed by both conventional and electroforming methods. Improvement in electrical performance has been found with antenna developed by electroforming method.

2. Electroforming Method

Electroforming is a process of reproduction of article by electro deposition upon a mandrel or mold that is subsequently separated from the deposit. [6]

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In electro forming process, pure metal is used as anode and the mandrel on which the metal is to be deposited is used as cathode as shown in schematic diagram, Fig.1.

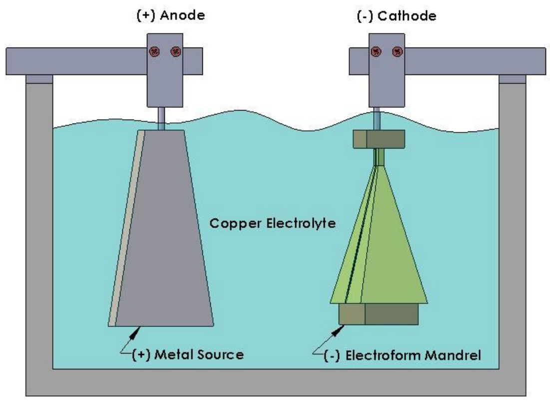

Fig. 1 Schematic Diagram of Electroforming

The difference between electroplating and electro forming is that in the former case, the metal permanently sticks to the cathode where as in the later case a solid shell is produced around the cathode which can be separated. The finish of the part produced will depend upon the surface finish of the mandrel.

Basic steps involved in electroforming are:

i. Mandrel design / Preparation
ii. Placement of mandrel in appropriate electroplating solution.
iii. Deposition of metal on mandrel by electrolysis process up to required thickness.
iv. Removal from the solution and machining of external surface.
v. Separation of mandrel from deposited metal
vi. Finishing of product

The advantage of the process is that it faithfully reproduces the form or mandrel exactly, to within one micron accuracy, without the shrinkage and distortion associated with other metal forming techniques such as casting, stamping or drawing. Since the mandrel is machined as an outside surface, close dimensional tolerances and high surface finishes can be held and maintained on complex interior configurations. It is a high precision additive manufacturing process capable of producing simple and complex shaped minute components of exceptionally high precision. High dimensional accuracy in complicated parts and high surface finish on internal surfaces are key features of electroforming process. It can produce pure as well as laminated metal components. The process is very useful for thin walled parts where higher accuracy and better surface finish is desirable. Seamless wave-guides and microwave frequency ridged horns can be made with close dimensional tolerance and high surface finish by electroforming method.

3. Development of Pyramidal Horn Antenna

Thin walled pyramidal horn antenna was developed by both conventional and electroforming methods. Development of horn antenna by milling and welding process proved beyond the process capability in achieving stringent tolerance and surface finish requirements. Hence electroforming method was adopted and successfully utilized in realization of antenna.

3.1 Manufacturing by conventional method

Conventional method of manufacturing pyramidal horn antenna involves machining of four aluminium alloy plates using milling and joining them by welding. Tapered ridges were machined on two plates and other two plates are having planar surface. To hold all four plates in required position during welding process, a guiding mandrel was fabricated depicting the internal shape of antenna over which all plates were clamped and carried-out welding of edges. Work piece holding problem during machining was faced because of thin plates with tapered ridges. Due to small thickness of ridged plate, joining by welding method created problems which lead to imprecision in dimensions and positional accuracies. Exploded view of antenna development by conventional method is shown in Fig. 2.

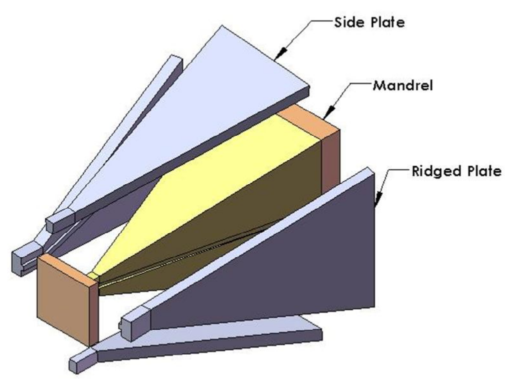

Fig. 2 Development of Horn Antenna by Conventional Method

3.2 Development by Electroforming Method

To manufacture ridged horn antenna with a tapered internal ridge, first a mandrel was prepared with Aluminum alloy material to the exact internal dimensions of the horn with close dimensional tolerance.

Copper material was deposited over the mandrel and mandrel dissolved after achieving required thickness deposition.

3.2.1 Design and manufacturing aspects of mandrel

The success of electroforming process will depend on the type of mandrel chosen and the material used in its fabrication. Surface finish of the mandrel plays an important role in electroforming as it reflects in the final product finish. The mandrel can be electrical conductor or non-conductor, permanent or expendable. Permanent mould can be easily machined from metal and is very economical. These can be used only when there is sufficient draft to withdraw them without any damage to the formed part. The expendable mandrels can be of low melting point alloys such as Bismuth free 92% Tin and 8%Zinc, Aluminium alloy and Zinc alloy or some chemically soluble substance. In permanent mandrels Nickel, Austenitic stainless steel, invar, Kovar, Copper, Brass can be used. Invar and Kovar are alloys having low coefficient of thermal expansion value and can be used for cases where high dimensional accuracy is required. Nonconductive mandrel can be made conductive in a number of ways. The most common method is to produce a chemically reduced film of silver to the surface of mandrel, and then carryout electro-deposition up to required thickness. Wax mould can also be used by coating with Graphite.

To develop pyramidal horn antenna by electroforming method an Aluminum alloy mandrel was manufactured. On tapered surfaces of electroforming mandrel tapered groove was machined replicating the ridge profile as shown in Fig. 3. Machining tail portion of mandrel was critical due to smaller cross section and had to machine with utmost care. Extra length was provided on both side of mandrel for holding purpose. The extra length portion of mandrel was painted to mask the surface from electroforming and these surfaces served as reference in post forming machining operation.

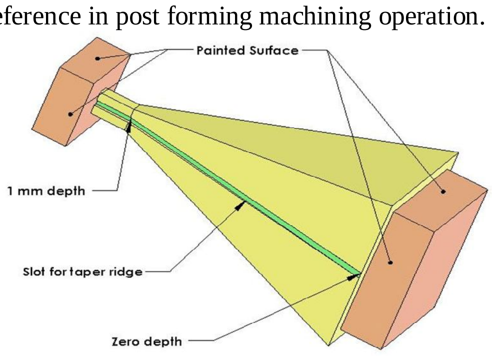

Fig. 3 Electroform Mandrel

3.2.2 Electroforming over horn antenna mandrel

The mandrel of pyramidal ridged horn antenna was cleaned in Trichloro ethylene to remove oil and grease and degreased in mild alkali solution. Then mandrel was dipped in dilute Nitric acid for neutralizing. Initially Zinc coating (immersion) over the mandrel was applied and Copper was deposited in cyanide bath for 10-15 minutes, followed by dipping in dilute acid solution. Rinsing operation followed each of the above steps. After these steps mandrel was electro deposited in copper sulphate bath to get required thickness as shown in Fig. 4. Mass deposited over mandrel is a function of

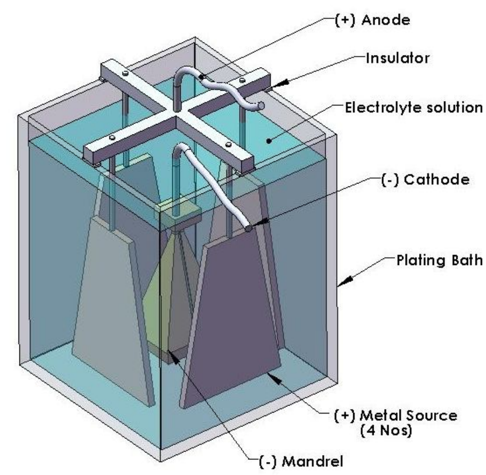

Fig. 4 Electroforming Setup

current density and time, in-turn these factors influences the quality of electroforming. The limitations in development of pyramidal horn antenna by electroforming method are slow rate of production and low mechanical strength as it is an atomic level additive process and made of pure metal.

3.2.3 Mandrel Removing Methods

Electroforms are removed from permanent mandrel with the techniques like, sudden impact, heating with hot oil either to melt or soften a parting compound or to take the advantage of favorable differential in Coefficient of Thermal Expansion (CTE) values of mandrel and the deposit. If mandrel has low CTE value it can be cooled for removal. Zinc alloys are dissolved out in Hydrochloric acid and Aluminum alloys are readily dissolved in hot sodium hydroxide solution. After machining the external electro-deposited surface of mandrel, it was dissolved in Sodium Hydroxide solution and finally horn antenna produced was plated with Silver.

4. Results

I. Surface finish and dimensional tolerance achieved on internal surface of Pyramidal microwave horn antenna developed by electroforming method is 0.07micron (Ra) and 10 microns respectively compared to 0.8 micron (Ra) and 100 microns for antenna developed by conventional method. Photographs of pyramidal horn antennas developed by conventional method and electroforming are shown in Fig. 5 and Fig. 6 respectively.

II. Antennas developed by both methods were tested for electrical performance and improvement in performance of antenna developed by electroforming method has been observed as shown in Fig. 7. The performance of antenna is evaluated by testing its Voltage Standing Wave Ratio (VSWR) versus frequency. The acceptable limit of VSWR value for this antenna is 3, and ideal condition value is 1. Antenna developed by conventional method exceeded the acceptable limit of VSWR 3, where as VSWR less is than 2 were observed for antenna developed by electroforming method.

Fig. 5 Horn Antenna Developed by Conventional Method

III. Enhancement in electrical performance has been observed in the antenna developed by electroforming.

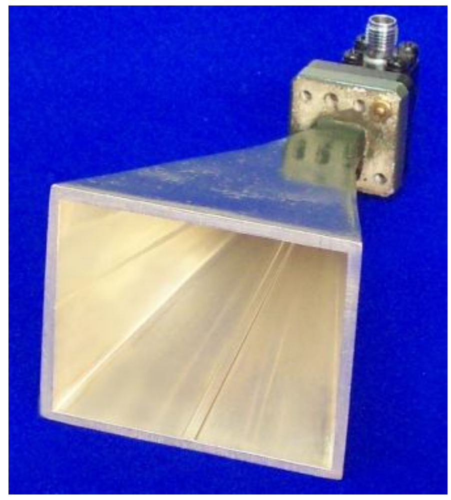

Fig. 6 Horn Antenna Developed by Electroforming Method

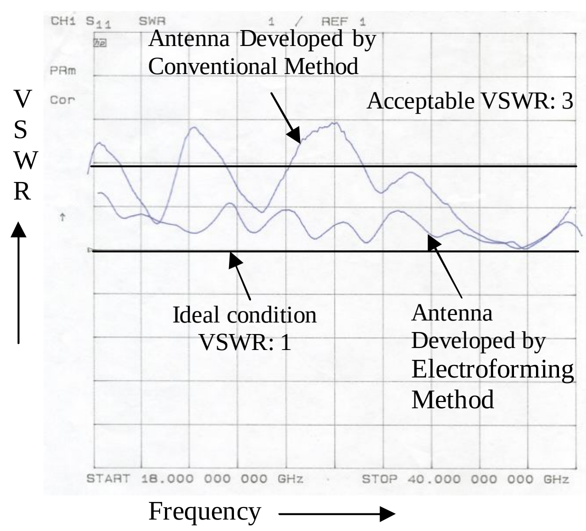

Fig.7 Comparative Result, Electrical Performance of Horn Antennas

5. Conclusions

Electroforming should be thought of as a basic manufacturing process when considering alternatives best suited for making any particular item with thin walled complex internal feature that requires high dimensional accuracy and surface finish. However the main drawback is that the rate of production is slow. The pyramidal horn antenna developed by electroforming method resulted in improved electrical performance compared to antenna developed by conventional method.

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