ADVANCED LOSS-REDUCTION TECHNIQUES IN MILLIMETER WAVEGUIDE INSTRUMENTS

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Abstract

Advanced techniques have been developed whereby cold hobbing and honing are applied in making and finishing millimeter waveguide instruments. This advancement significantly improves the characteristics of waveguides and cavity frequency meters.

Introduction

It is possible to make wide-band rectangular waveguide instruments for the millimeter wave band by simply scaling down conventional microwave instruments such as frequency meters, attenuators, directional couplers, etc., electroforming on aluminum or stainless steel mandrels, and using a general-purpose precision machine tool such as a jig borer. However, the surface finish obtained by these techniques is often not fine enough for millimeter wave instruments and productivity is not satisfactory.

Recently, it has become feasible to efficiently produce wide-band and low-loss millimeter wave instruments by the extensive use of manufacturing techniques such as cold hobbing, precise boring, electric discharge machining, honing of inside of waveguide, etc.[1] Typical examples are reported below.

Tolerance and Surface Roughness

In the design and fabrication of low-loss waveguide instruments at the millimeter wavelengths, special considerations regarding the dimension tolerance and surface roughness are essentially required. The shorter the wavelength, the smaller size and tolerance of waveguide instruments is required. The skin depth of a conductor decreases in porportion to the square root of the wavelength. Thus, a tolerance of less than 10 μm is usually required for instruments operating in the millimeter wave band of 30 to 110GHz, where the skin depth of silver or copper is about 0.2 to 0.4 μm. The roughness of wall surface should be sufficiently less compared with the skin depth, if the increase of heat loss caused by rf resistance on the wall surface of waveguide is to be kept to a low level.

Cold Hobbing

Cold hobbing is a method for making metal parts by plastic deformation caused by strongly pressing a tool called a hob to the workpiece. The basic process is illustrated in Fig. 1. A product with a mirror finished silver surface can be obtained by previously cladding the surface of the workpiece with a silver layer.

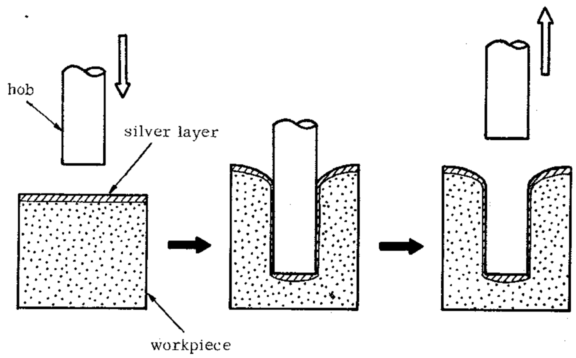
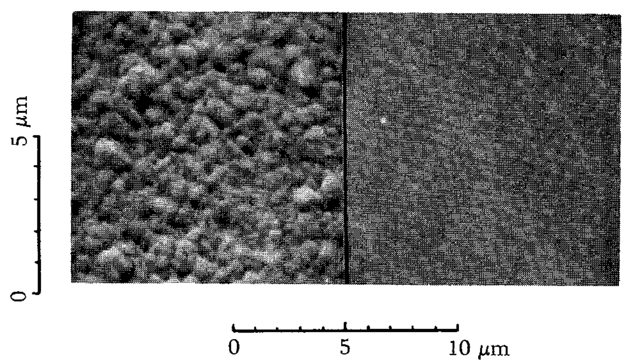


Fig. 1 Basic process of cold hobbing



(a) Electroformed copper with average 3 μm thick silver plated

(b) Cold hobbed silver-clad copper

photographed by scanning electron microscope
magnification: 4,000

Fig. 2 Comparison of surface roughness

Tolerances of ±2 to 5 μm and surface roughness of 0.02 to 0.05 μm can be obtained by cold hobbing under proper conditions. Moreover, the productivity by cold hobbing is undoubtedly of a much higher quality than that by electroforming or ordinary machining.

Magnified photographs of the surfaces obtained by both cold hobbing a silver-clad metal and silver plating after electroforming are shown in Fig. 2. These photographs magnified 4,000 times were taken by means of a scanning electron microscope. This observation technique of the surface roughness is much more accurate and practical than the mechanical probe method.

Cold hobbing is suitable for making cavity resonators, tapered waveguides, waveguide grooves, etc., and is a technique that will contribute to improving the precision of frequency meters and decreasing the conductor loss in attenuators, phase shifters, waveguides, etc. Fig. 3 shows the quality factors of a cavity resonator made by the conventional electroforming and one made by the cold hobbing process. It also shows the relation between skin depth and surface roughness of a cavity obtained by respective processes.

Honing

Usually the surface roughness of the inside of drawn rectangular wavguides for millimeter wavelengths is about 0.t μm. A simple means to improve this surface roughness has been in demand.

Honing and polishing are promising methods for finishing the inside of thin pipes, and the recent extrusive honing has proved to be an effective process for finishing the inside of waveguides for millimeter waves. In this extrusive honing a claylike soft elastomer mixed with abrasives is forced into and extruded from waveguides. When properly applied, this process will improve the surface finish of the inside of millimeter wave rectangular waveguides to about 0.8 μm. This process will also be effective for plated waveguides. Fig. 4 shows the measured values and theoretical values of loss of typical millimeter wave waveguides. In the case of WR-12 waveguide with the surface improved by honing, the average loss value at 90 GHz was only 1.23 times the theoretical value.

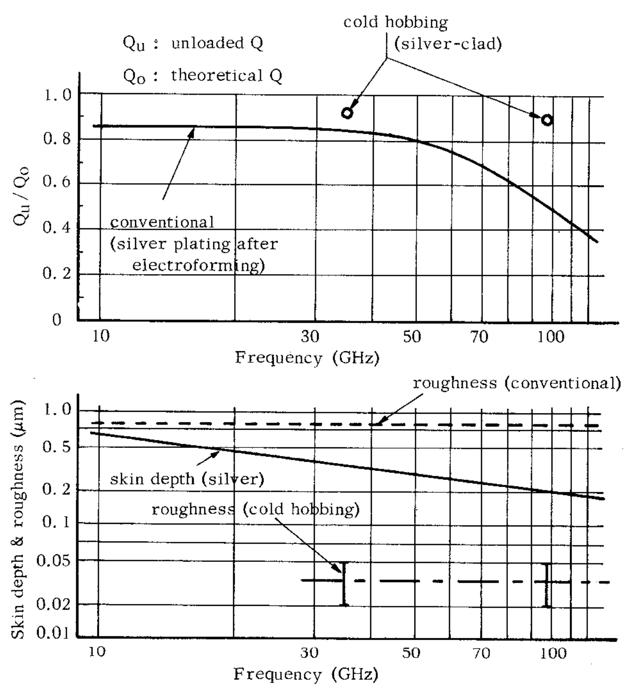


Fig. 3 Q's of circular TE_{111} resonant cavities, skin depth and actual surface roughness

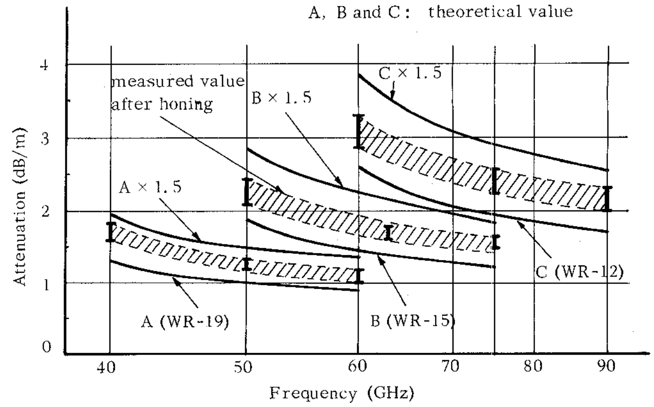


Fig. 4 Attenuation of rectangular waveguide with silver plating

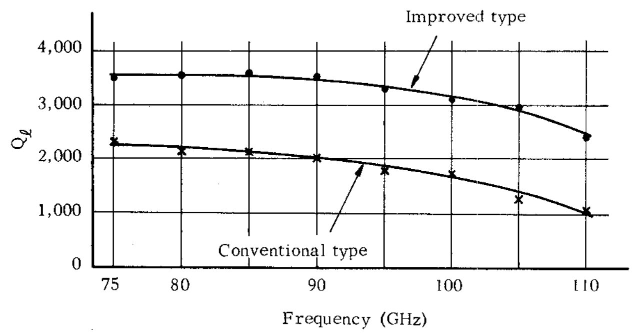


Fig. 5 Improvement of frequency meter using TE_{111} cavity

High-Q Cavity Frequency Meter

A direct-reading, cavity frequency meter for the band of 75GHz to 110GHz has been fabricated to which the above-mentioned technique is applied. This frequency meter employs a circular TE_{111} resonant cavity which is made of silver-clad metal by cold hobbing.

Fig. 5 shows the characteristics of Q of the frequency meter over the frequency range of 75 to 110GHz. It also shows the characteristics of a conventional frequency meter with an electroformed cavity. It is noted that Q_ℓ (loaded Q) is almost twice as great as that of the conventional one. Therefore, the frequency resolution is improved to almost twice that of the conventional frequency meter.

Conclusion

Low-loss rectangular waveguides and high-Q resonant cavities have made and tested in the millimeter wave gand up to 110GHz. Cold hobbing and honing have proved to be effective manufacturing techniques with high quality productivity for low-loss millimeter wave instruments. The surface of a conductor with a fine finish is observed accurately by a scanning electron microscope.

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Reference

(1) K. Ohi and I. Ohtomo, "Loss reduction of millimeter wave circuits," 1974 Joint Convention Record of Four Institutes of Electrical Engineers. Japan.