

# The Design of Acoustic Horns for Ultrasonic Aided Tube Double Side Flange Making

Kuen-Ming Shu, Jyun-Wei Chen

**Abstract**—Encapsulated O-rings are specifically designed to address the problem of sealing the most hostile chemicals and extreme temperature applications. Ultrasonic vibration hot embossing and ultrasonic welding techniques provide a fast and reliable method to fabricate encapsulated O-ring. This paper performs the design and analysis method of the acoustic horns with double extrusion to process tube double side flange simultaneously. The paper deals with study through Finite Element Method (FEM) of ultrasonic stepped horn used to process a capsulated O-ring, the theoretical dimensions of horns, and their natural frequencies and amplitudes are obtained through the simulations of COMOSOL software. Furthermore, real horns were fabricated, tested and verified to proof the practical utility of these horns.

**Keywords**—Encapsulated O-rings, ultrasonic vibration hot embossing, flange making, acoustic horn, finite element analysis.

## I. INTRODUCTION

ULTRASONIC facilities have been widely used in machining [1], welding [2], wire bonding [3], ultrasonic lubrication [4], etc. These ultrasonic machining systems are composed by the generator and the ultrasonic converter (transducer, cone and horn). The cone and horn device are necessary because the amplitudes provided by the transducers themselves are insufficient for most practical applications of power ultrasound [5].

An ultrasonic horn is a tapering metal bar commonly used for augmenting the oscillation displacement amplitude provided by an ultrasonic transducer operating at the low end of the ultrasonic frequency spectrum. Another function of the ultrasonic horn is to efficiently transfer the acoustic energy from the ultrasonic transducer into the treated media, which may be solid or liquid [6].

Ultrasonic horn of different profiles such as Gaussian [7], Fourier, exponential [8], stepped [9], [10], sinusoidal [11], conical, catenary [12] and spline [13], have been proposed and investigated by many researchers. The most frequently used shapes of ultrasonic horns are: cylindrical, tapered, exponential and stepped.

Maximum achievable ultrasonic amplitude depends, primarily, on the properties of the material from which an ultrasonic horn is made as well as on the shape of its longitudinal cross-section. Commonly, the horns are made from titanium alloys, such as Ti6Al4V, or aluminum alloys.

Kuen-Ming Shu is with the Dept. of Mech. and Computer-Aided Eng., National Formosa University, Taiwan (phone: 886-5-6315327; fax: 886-5-6315310; e-mail: kmshu@nfu.edu.tw).

Jyun-Wei Chen is with the Dept. of Mech. and Computer-Aided Eng., National Formosa University, Taiwan.

Encapsulated O-rings are specifically designed to address the problem of sealing the most hostile chemicals and extreme temperature applications. Encapsulated O-rings consists of a solid or hollow elastomeric core encapsulated in a polytetrafluoroethylene (TEFLON) sheath. To process TEFLON sheath, a tube flange or mating surface perpendicular to the long axis of the tube is need, it can be processed by ultrasonic machining method. The aim of this paper is to design and fabricate a horn for ultrasonic aided tube flange making by employing COMOSOL finite element software.

## II. ANALYSIS OF TWO CYLINDERS CONNECTED WITH AN CURVE HORN

The horn is usually designed to have a higher amplitude/velocity at the tip so as to provide sufficient amplitude for machining. For conception and achievement of ultrasonic assembly, all the elements that compose the ultrasonic chain must be properly sized for that the system to perform at the resonant frequency. For this is necessary to cover the following steps [14]:

- frequency selection;
- determination of the sound propagation velocity in the selected material;
- calculation of the theoretical dimensions;
- realization of the documentation needed for execution of the ultrasonic assembly;
- achievement of the prototypes, accords, and test case of our experimental data.

The design of an acoustic horn depends on the determination of the resonance length. The length must equal to the multiple of half wavelength of the system. The resonance length of an acoustic horn depends on the areas of input and output end, wavelength constant, etc. The resonance equations and amplitude magnifications of two cylinders connected with a curve are presented.

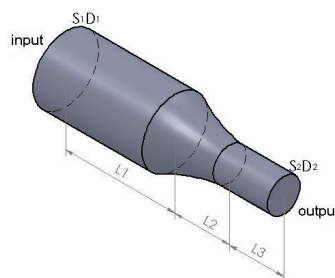


Fig. 1 Stepped horn - two cylinders connected with a curve

Fig. 1 depicts the profile of a two cylinders connected with

a curve horn. Its resonance equation can be obtained by [15]:

$$\tan \alpha l_1 = \frac{\frac{S_2 \tan \alpha l_3 + \frac{S_3 \tan \alpha l_2}{S_1}}{1 - \frac{S_3 \tan \alpha l_2 \tan \alpha l_3}{S_2}}}{S_3} \quad (1)$$

Finally, the amplitude magnification M can be calculated by:

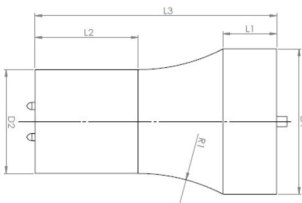
$$M = \left| \frac{u_3}{u_1} \right| = \frac{S_1 \cos \alpha l_2}{S_3 \sin \alpha l_3} = \frac{S_1}{S_3} \frac{1}{\sqrt{1 + \left[ \left( \frac{S_2}{S_3} \right)^2 - 1 \right] \cos^2 \alpha l_3}} \quad (2)$$

where  $\alpha (= \omega/c)$  is the wavelength constant, M is the amplitude magnification, and S1 and S2 are the cross section areas of the input end and output end, respectively.

Let  $l_1 = \lambda/4$ , the working frequency f is set to be 20 kHz, the sound velocity c is set to be  $5.2 \times 10^5$  cm/s

Using the input data mentioned above, the dimensions and amplitude magnification of stepped horn are shown in Table I.

TABLE I  
 THE DIMENSIONS AND AMPLITUDE MAGNIFICATION OF STEPPED HORN



Dimensions (mm)	Value
D1	70
D2	50
L1	26
L2	50
L3	117
R1	90
amplitude magnification	2.4

### III. RESULTS AND DISCUSSION

Finite element method (FEM) is used by engineers to model, analyzed, and predicts the performance of real physical systems. The accuracy of the model depends not so much on the particular analytical technique, but on the assumptions made in modelling the physical system. The finite element analysis was performed by using the commercially available code COMOSOL Multiphysics, it is one of the most flexible and powerful tools available for solving the horn design problems [16].

The horn for tube flange making is designed as two cylinders connected by a curve. This work computed the theoretical dimensions according to the diameter ratios of commercial horns. Their natural frequencies obtained by the modal analysis are shown in Table II.

TABLE II  
 NATURAL FREQUENCIES OF STEPPED HORN

Mode	Horn frequency (Hz)
1st modes	11741
2nd modes	11742
3rd modes	20105
4th modes	22391
5th modes	22392

According to the requirement of finite element analysis approach, the horn has to be divided into simple, homogeneous, discontinuous finite mesh, the smaller the mesh element size is, the more accurate the results of an analysis will be. But when used elements are too small, the meshing will generate too many elements and too time-consuming to be happen. Fig. 3 shows extremely coarse meshing and Fig. 4 shows extremely fine meshing.

Regarding the sonotrode modal shapes and the relative amplitude at resonance frequency is shown in Fig. 5. A good agreement result obtained from COMOSOL has been found as 20105 Hz.

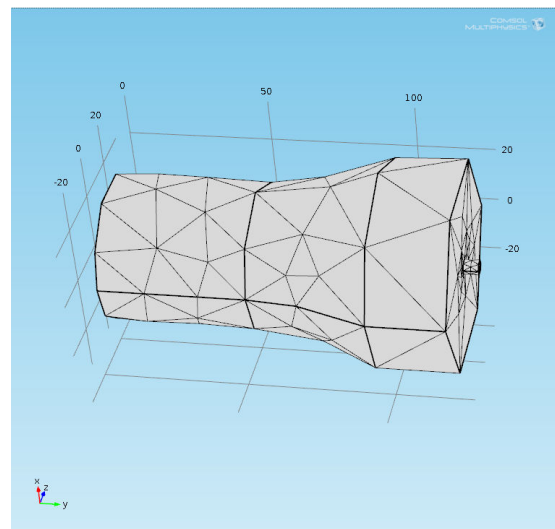


Fig. 3 Finite element model of stepped horn -COMSOL meshing extremely coarse

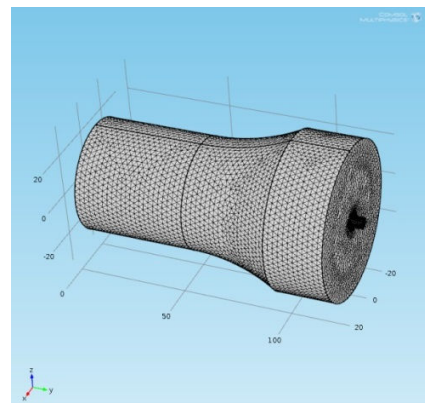


Fig. 4 Finite element model of stepped horn -COMSOL meshing extremely fine

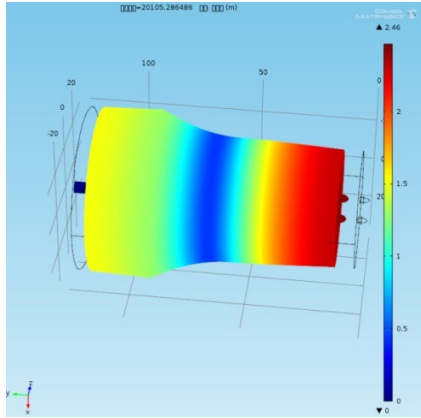


Fig. 5 Modal frequencies of a stepped horn

The natural frequencies of the horn computed by equation are closer to the operating frequency 20 kHz. Experiments are currently being set up to verify the validity of the analytical results. Fig. 6 shows the real horn made by aluminum. Due to its high strength and stability in properties, the A7075-T651 aluminum alloy is used as the horn material, its properties are elastic modulus  $E = 71.7 \text{ GPa}$ , Poisson ratio  $\mu = 0.33$ , and mass density  $= 2810 \text{ kg/m}^3$ . Fig. 7 shows the ABS bottom die made by 3D printing machine, and with 0 to 30 degree inclination angle. These horn and die are set on the specialized station for ultrasonic aided tube flange making as shown in Fig. 8.



Fig. 6 The real horn made by aluminum

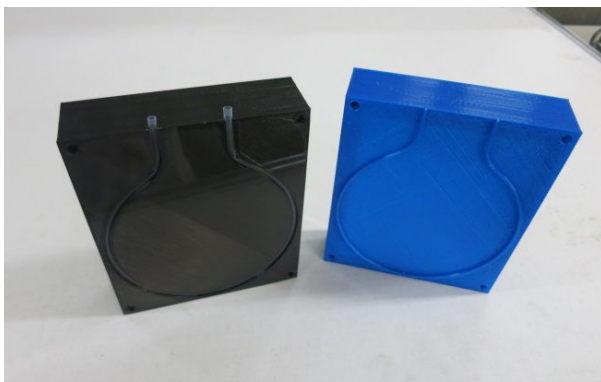


Fig. 7 Bottom dies set



Fig. 8 Ultrasonic tube flanging specialized station

Fig. 9 shows the relationship between bottom die set inclination angle and spring back angle of tube flange, it depicts that the optimum bottom die set inclination angle is 19-24 degree when 20KHz ultrasonic frequency was selected.

The flanged tube of Teflon with 4mm diameter was shown in Fig. 10.

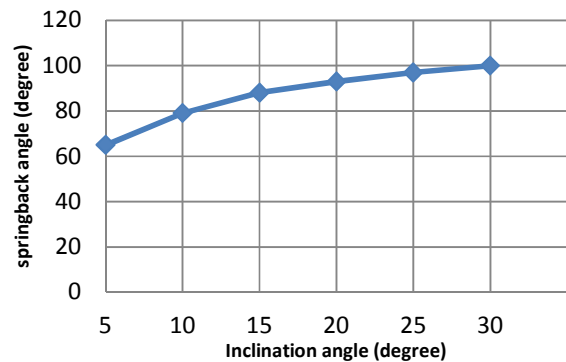


Fig. 9 The relationship between inclination angle and spring back angle



Fig. 10 The flanged tube of Teflon with 4mm diameter

#### IV. CONCLUSIONS

This paper performs the design and analysis method of the acoustic horns with double extrusion to process tube double side flange simultaneously. Theoretical and numerical analysis was conducted to study the performance of ultrasonic horns.

From the results of analysis, the natural frequency of the horn designed by the equation is close to the operating frequency of the machine. The horn designed by the proposed method will use less material and trial & error time. Real aluminum horns are made and be approved working effectively on the ultrasonic tube flanging specialized station.

**Jyun-Wei Che** is a research assistant in National Formosa University.

#### ACKNOWLEDGMENT

The authors would like to thank for the financial support from National Science Council in Republic of China under the contract number of MOST102-2221-E-150-035

#### REFERENCES

- [1] P. L. Guzzo, A. H. Shinohara and A. A. Raslan, "A Comparative Study on Ultrasonic Machining of Hard and Brittle Materials," *J. of the Braz. Soc. of Mech. Sci. & Eng.*, vol.26, 2004, pp.56-61.
- [2] L. Parrini, "Design of advanced ultrasonic transducers for welding devices," *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control* vol. 48, 2001, pp.1632-1639.
- [3] L. Parrini, "New technology for the design of advanced ultrasonic transducers for high-power applications," *Ultrasonic* vol.41, 2003, pp.261-269.
- [4] A. Iula, G. Caliano, A. Caronti, M. Pappalardo, "A power transducer system for the ultrasonic lubrication of the continuous steel casting," *IEEE Transactions on Evolutionary Computation* vol.50, 2003, pp.1501-1508.
- [5] D. A. Wang, W. Y. Chuang, K. Hsu, H. T. Pham, "Design of a Bezier-profile horn for high displacement amplification," *Ultrasonic*, vol.51, 2011, pp.148-156.
- [6] Peshkovsky, S.L. and Peshkovsky, A.S., "Matching a transducer to water at cavitation: Acoustic horn design principles," *Ultrasonic. Sonochem.*, vol.14, 2007, pp.314-322.
- [7] C.-H. Lee and A. Lai, "Silicon ultrasonic horns for thin film accelerated stress testing," *Proceedings of 2001 IEEE Ultrasonics Symposium*, 2001, pp.867-870.
- [8] E. Eisner, "Design of sonic amplitude transformers for high magnification," *The Journal of the Acoustical Society of America* vol.35, 1963, pp.1367-1377.
- [9] A. Bangviwat, H.K. Ponnekanti, R.D. Finch, "Optimizing the performance of piezoelectric drivers that use stepped horns," *The Journal of the Acoustical Society of America* vol.90, 1991, pp.1223-1229.
- [10] D. Sindayihebura, L. Bolle, "Theoretical and experimental study of transducers aimed at lowfrequency ultrasonic atomization of liquids," *The Journal of the Acoustical Society of America* vol.103, 1998 pp.1442-1448.
- [11] B.N. Nagarkar, R.D. Finch, "Sinusoidal horns," *The Journal of the Acoustical Society of America*, vol.50, 1971, pp.23-31.
- [12] K.F. Graff, "Wave Motion in Elastic Solids," The Clarendon Press, Oxford, 1975.
- [13] V. Salmon, "A new family of horns," *The Journal of the Acoustical Society of America* vol.17, 1946, pp.212-218.
- [14] Alexandru Sergiu Nanu, Niculae Ion Marinescu and Daniel Ghiculescu, "Study on Ultrasonic Stepped horn Geometry Design and FEM Simulation," *Nonconventional Technologies Review*, vol.4, 2011.
- [15] Simakawa M., *The principles and practices of ultrasonic engineering (in Chinese)*, Fu Han Co., Taipei, 2001, p.113.
- [16] <http://www.comsol.com/comsol-multiphysics>

**Dr. Kuen-Ming Shu** joined National Formosa University in 1985, where he is currently an professor. His interesting is in nontraditional machining.