Application for Simulating Acoustic Response of Condenser Microphone Cartridges



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Project Overview

Purpose:

Reduce number of design iterations to shorten project length for new condenser microphone designs

Goals:

- Use COMSOL to model the frequency and spatial response of a directional condenser microphone cartridge
- Make the model parameterizable and create a GUI for ease of use

Challenges

- Figure out how to build model in a way that geometry changes won't 'crash' it or require setting up the entire model again
- Keep solve time reasonable (minutes) while still getting a result that is close enough to reality that it is worthwhile

What is a Condenser Microphone?

- Transducer that converts sound to electrical signal using electrostatic energy
- Like a parallel plate capacitor, but one of the plates is a moveable diaphragm
 - Output is proportional to the change in the distance x between the diaphragm and backplate
 - $\tilde{v} = E * \left(\frac{\Delta C}{C_0}\right) = E * \frac{\Delta x}{x_0}$
- Acoustical networks designed to tune the response of the diaphragm to incoming sound
- Pressure difference at front and back as well as the phase shift network of a cavity and acoustic resistance creates directional response



Application Display and User Interface

- GUI create with Application Builder
- Series of textboxes and radio buttons to create the geometry
- Parts are a series of stacked cylinders
- Backplate and Resonator geometry setup as series of annular holes
- Multiple view options
- Set source distance and frequencies
- Can save to edit it in model viewer

Simulation Parameters Simu	lation Results							
ieometry View:	Cartridge Full Cartrid	ige Cros	s Section 🔘 Diaphragm/S	pacer/Backplate Only	Cavity/Resistar	nce Port Only 🔘 Cartridge Insides Only		
Cartridge Parame	eters		Source	e Parameters		Show Progress Form	Save as COMSOL Model File	(.mph)
artridge Template: 1/2	Inch Cardioid w Resonator	•	Distance From Source:	24	in	A		
Front Entry Port / R	esonator Parameters		Frequency Resolution:	Octave	•		=	
lesonator Hole/Front Entry Depti	.015	in	Angle(s) of Incidence:	0 Deg Only	•	Mesh Geometry	Run Simulation	
esonator Hole/Front Entry Diam	eter: 0.1	in	Q Q Q + + +	· • [xy, [yz, [xz,]]	0.			
Single Front Port •	Multiple Front Ports (Resonato	r)						
enter Hole for Resonator?	\checkmark							
lumber of Annualar Resonator H	oles: 4							
esonator Hole Annular Pattern D	iameter: 0.35	in						
Diaphragm / Spacer /	Backplate Parameters					0.7		
Diaphragm Ring Inner Diameter:	0.44	in				0.2		
Diaphragm Ring Height:	0.038	in					in	
Diaphragm Resonance:	8300	Hz		-				
iaphragm Material Properties:	View/Edit Material Proper	ties						
pacer Washer Thickness:	0.002	in						
lackplate Voltage:	180.0	v		1//				
lackplate Thickness:	0.021	in					-0.2	2
lackplate Hole Diameter:	0.04	in						
lumber of Annular Backplate Ho	es: 4			AC				0.1
lackplate Annular Hole Pattern D	ameter: 0.316	in			-			0.1
Center Hole for Backplate?	~			F				0.0
Phase Shift Net	work Parameters							
Omni-Directional Oun	-Directional 🔘 Bi-Directiona	í						0
Phase Shift Network Cavity Heigh	t: 0.018	in						
hase Shift Network Cavity Diame	ter: 0.4	in					0.2	
lesistance Port Height:	0.040	in						
Resistance Port Diameter:	0.145	in					0	
lesistance (Measured on Manom	eter): 1100	cgs					in	
tesistance Location in Port:	🔘 Top 🖲 Bottom					-0.2		
Rear Port / Cartridge	Housing Parameters		7					
tear Port/Crimp Depth:	0.01	in	У 1 - х					
Cartridge Outer Diameter:	0.5	in						
	0.35	1.00						

Application Display and User Interface

- Results tab shows response plot
 - Plot frequency response, polar or static diaphragm displacement
 - Cartridge Capacitance shown
- Save frequency response data as a .txt file for post processing
- Save COMSOL generated report with geometry parameters and results in a .docx format



Parameterized Geometry

- All geometry is created and selected using parameters
- Limiting, but drastically simplifies geometry creation and allows for easy modifications



Gray –	Green –	Blue –	Brown –
Cartridge Housing	Diaphragm Ring Cavity	Backplate Holes	Resistance Port
Yellow –	Orange –	Purple –	Pink –
Front Entry / Resonator	Spacer Washer	Phase Shift Cavity	Rear Entry / Crimp



a			
Setting	5		
Parameter	s		
Label: Loca	tion Parameters		
 Parame 	ters		
T di di litte			
Name	Expression	Value	Description
rs	r_s + cart_h	0.6127 m	Distance from Source to Front of Cartridge
air_z	-cart_h	-0.0031039 m	Surrounding Air Location
bp_z	cav_z+cav_h	0.0010516 m	Backplate Location (z)
sp_z	bp_z + bp_h	0.0017374 m	Spacer Washer Location (z)
diap_z	sp_z + sp_h	0.0017882 m	Diaphragm Location (z)
rport_z	crimp_z + crimp_h	4.4958E-4 m	Resistance Port Location (z)
cav_z	rport_z + rport_h	7.9756E-4 m	Cavity Location (z)
cart_z	0	0	Cartridge Bottom Location (z-direction)
crimp_z	0	0	Crimp Bottom Location
frnt_z	diap_z +diap_ring_h	0.0028042 m	Front Entry Location (z)
top_z	frnt_z + frnt_h	0.0031039 m	

PMI Edges Geometry 1 Surrounding Air (cyl12) Cartridge Housing (cyl16) Front Cavity (Diaphragm Ring) (cyl10) Front Entry/Resonator Port (cv(11)) Resonator Hole Radius (mov5) Rotate (Resonator Holes) (rot2) Resonator Openinings Objects (boxsel4) Partition Objects 2 (par2) Air Gap and Diaphragm Surface (cyl1) Backplate Hole(s) (cyl13) Phase Shift Network Cavity (cyl9) Backplate Hole Radius (mov4) Rotate (Backplate Holes) (rot1) BP Holes Object (cylsel4) Partition Objects 1 (par1) Resistance Port (cyl14) Housing Crimp Inner (cyl19) Partition Objects 3 (par3) Work Plane 1 (wp1) Work Plane 2 (wp2) Partition Domains 1 (pard1) Partition Domains 2 (pard2) Form Union (fin)

Model Geometry and Mesh

- Meshing is controlled by geometry selections
- Swept mesh used through the diaphragm/backplate air gap and in perfectly matched layer in bounding air volume around the cartridge
- Moving mesh applied to diaphragm
- Boundary Layers applied to backplate hole and air gap boundaries



Physics and Multiphysics Couplings Applied

Multiphysics

- Thermoviscous Acoustics applied between diaphragm and backplate account for losses in thin air gap region
- Diaphragm uses Membrane Physics
 - Couples to both Acoustics Physics on one side each
- Electrostatics and Electrical Circuit
 - Diaphragm is grounded
 - Bias Voltage applied through circuit
- Reference COMSOL Model: Brüel & Kjær 4134 Condenser Microphone
- Coupled to Pressure Acoustics for the rest of the model
 - Air outside of cartridge allows for diffraction to be accounted for
 - Allows phase difference between sound at front and back to be accounted for



Model Study and Results

- Two study steps
 - Stationary solves for electrostatic force and deflection of diaphragm
 - Frequency Domain Perturbation solves for mic response to incoming pressure wave
- Study parameters set in application
 - Frequencies, Auxillary Sweep of Incidence Angles
- Generates plots for the results window
 - Static Diaphragm Displacement
 - Frequency Response
 - Polar Response (if study set for it)



Study 1 (Diaphragm Modes)
 Step 1: Eigenfrequency
 Solver Configurations
 Study 2 (Frequency Response)

C Step 1: Stationary

Solver Configurations
 Study 3 (1kHz Sensitivity)
 Step 1: Stationary

Solver Configurations
 Study 4 (Polar Plot)
 Step 1: Stationary

Step 2: Frequency Domain Perturbation

Step 2: Frequency Domain Perturbation

Step 2: Frequency Domain Perturbation

Validation of Sample Half Inch Design

- As a quick check of the model, simulation of a design was compared to a measured prototype
- ¹/₂" diameter, cardioid polar pattern cartridge built and tested
- Model simplifies features of the geometry, but created quickly
 - Some edges chamfered and features like contact pin omitted
 - Phase shift network cavity geometry simplified
 - Acoustical parameters measured and included





Validation of Sample Half Inch Design

- Simulation vs Measured difference is only a dB or two at most frequencies
- Simulated Solid lines; Measured Response Dashed lines



freq=500 Hz

freq=1000 Hz

– frea=4000 Hz

500 Hz Measured

1 kHz Measured

• 4 kHz Measured

Conclusion

- Parameterized geometry and the application GUI can drastically simplify a complex model and allow for quick edits
- Directionality of a microphone cartridge can be simulated well in COMSOL
- Condenser cartridge frequency responses can be simulated with a reasonable correlation to built prototypes
- Methodology in the model could be used to simulate more complex geometries
- Additional Work: examining thermal losses in the phase shift network cavity for smaller designs



Thank You!

Questions?