Simulation of Rubber Grommets and Correlation with Test at Low Frequencies

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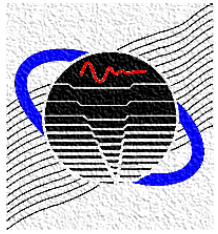
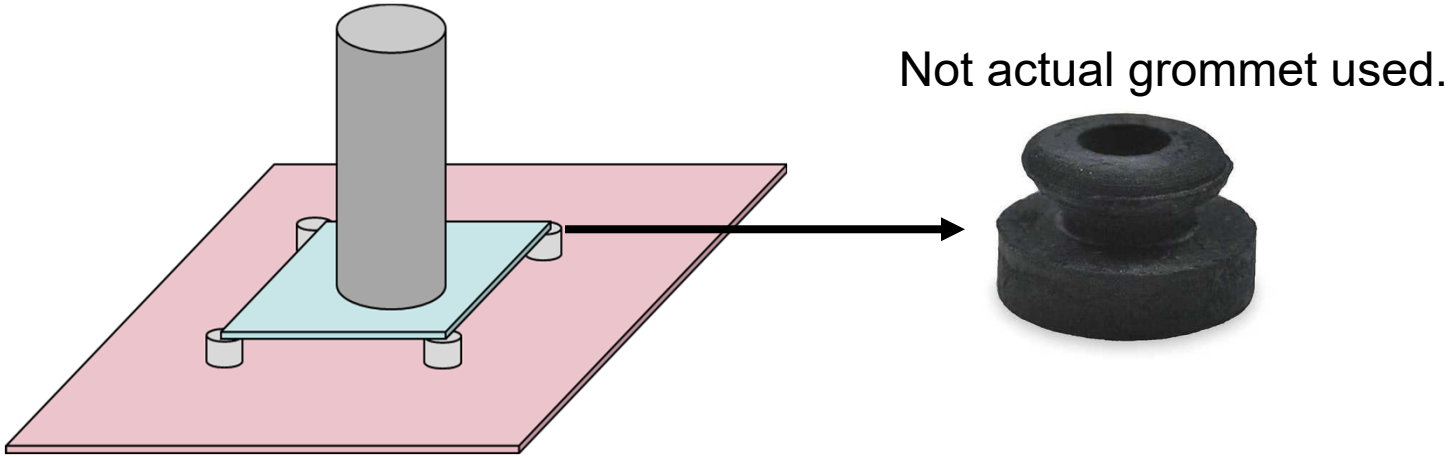


Compressor Noise Paths Outdoor HVAC

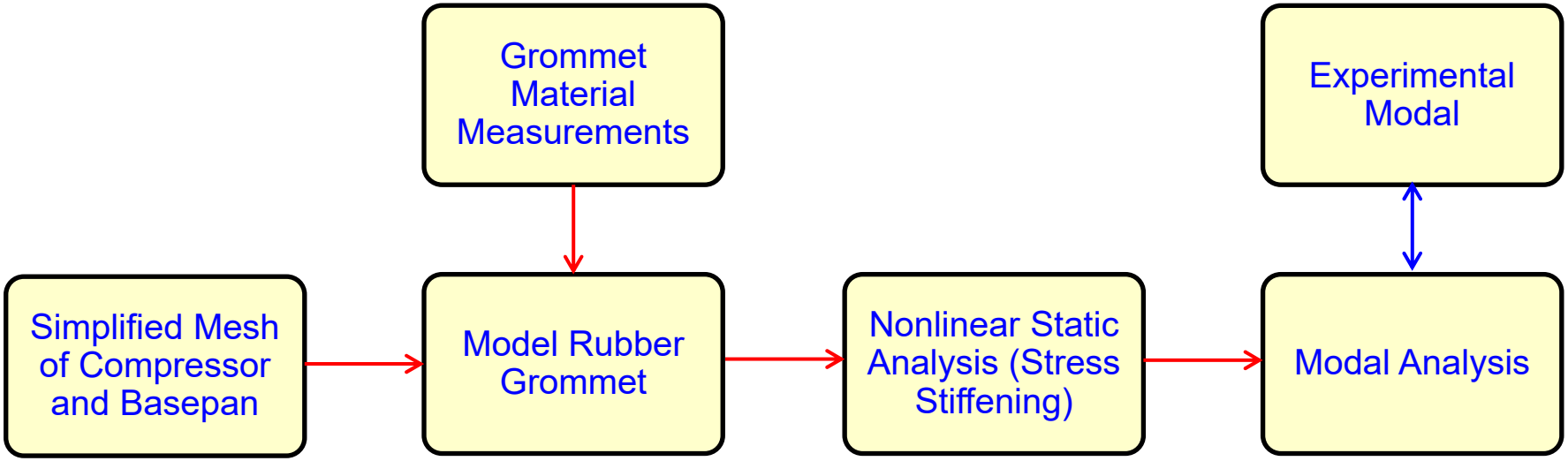
- Structureborne compressor → basepan → basepan radiation
- Airborne from compressor shell

Problem Compressor Isolation



- Isolate the compressor from the basepan.
- Prevent excessive vibration of the compressor which can damage the refrigeration tubing.
- For isolation, it is preferable that the grommets are as soft as possible whereas stiff grommets are favored for structural stability.
- Iterative testing is normally relied upon.

Simulation Workflow

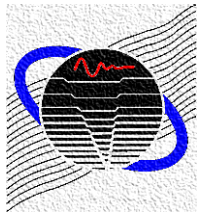


Ogden Model

The strain energy potential is expressed as

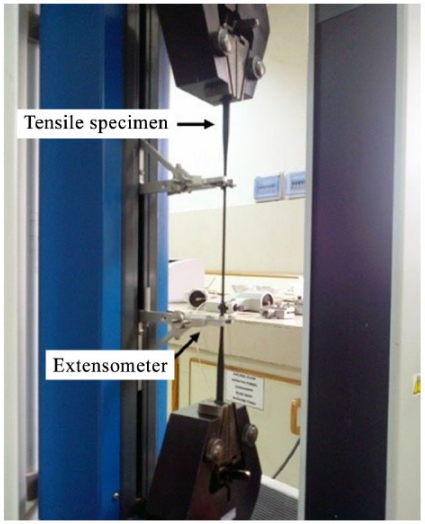
$$W = \sum_{i=1}^{3} \frac{\mu_i}{\alpha_i} \left(\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3 \right)$$

where $(\lambda_i)_{(i=1,3)}$ are the principal stretches and are directly measurable. The six constants to be determined are α_i and μ_i where $i = 1,2,3$.

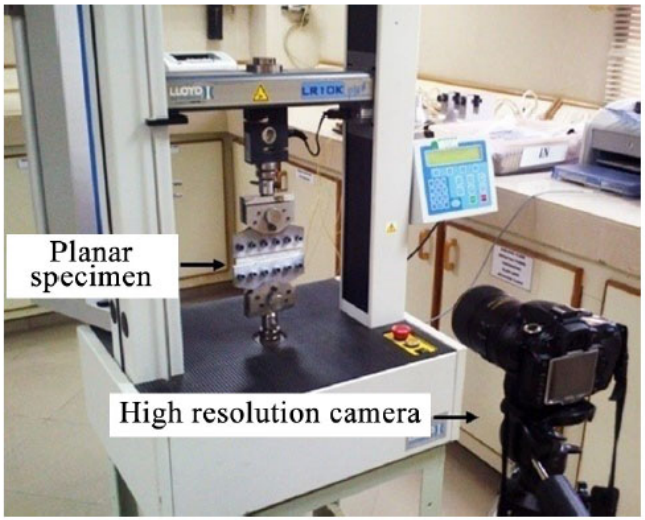


Shahzad et al., 2015

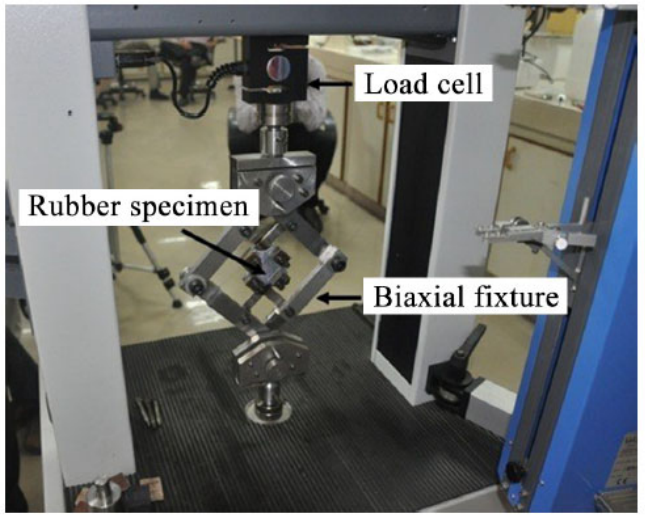
Material Testing



Uniaxial



Planar

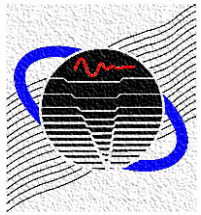


Equibiaxial

Simulate Uniaxial Test

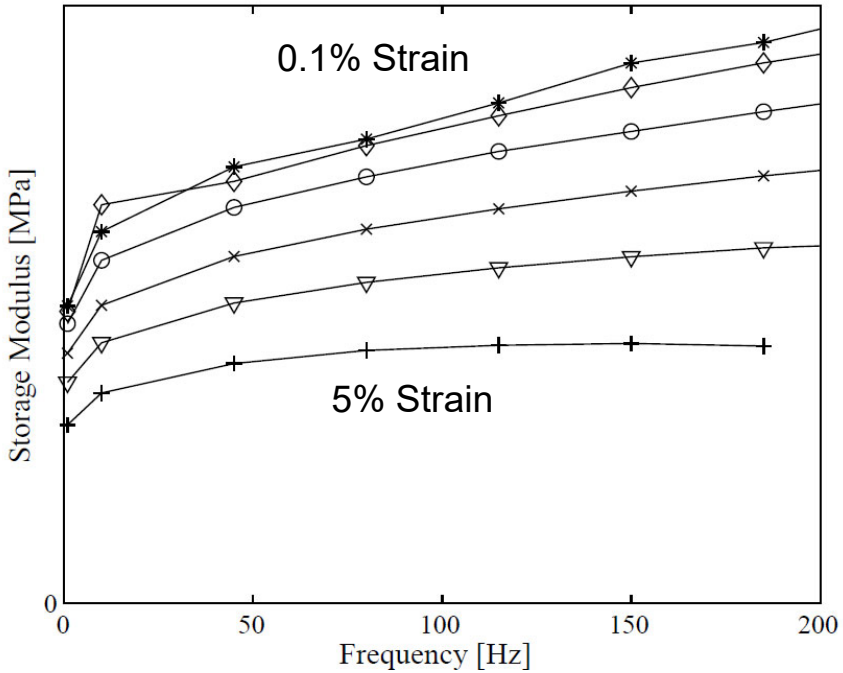
Model is most easily adjusted by multiplying Ogden Parameters by a constant.

Engineering Strain due to Imposed Displacement	**Engineering Stress $(\sigma_z)_1$ assuming: $\mu_1 = 0.6639$ MPa $\mu_2 = -0.0522$ MPa $\mu_3 = 0.0038$ MPa**	**Engineering Stress $(\sigma_z)_2$ assuming: $\mu_1 = 1.7 \times (0.6639)$ MPa $\mu_2 = 1.7 \times (-0.0522)$ MPa $\mu_3 = 1.7 \times (0.0038)$ MPa**	**Ratio of Stresses $\frac{(\sigma_z)_2}{(\sigma_z)_1}$**
0.2	0.3340	0.5677	1.7
0.6	0.7737	1.3152	1.7
1.0	1.0903	1.8532	1.7



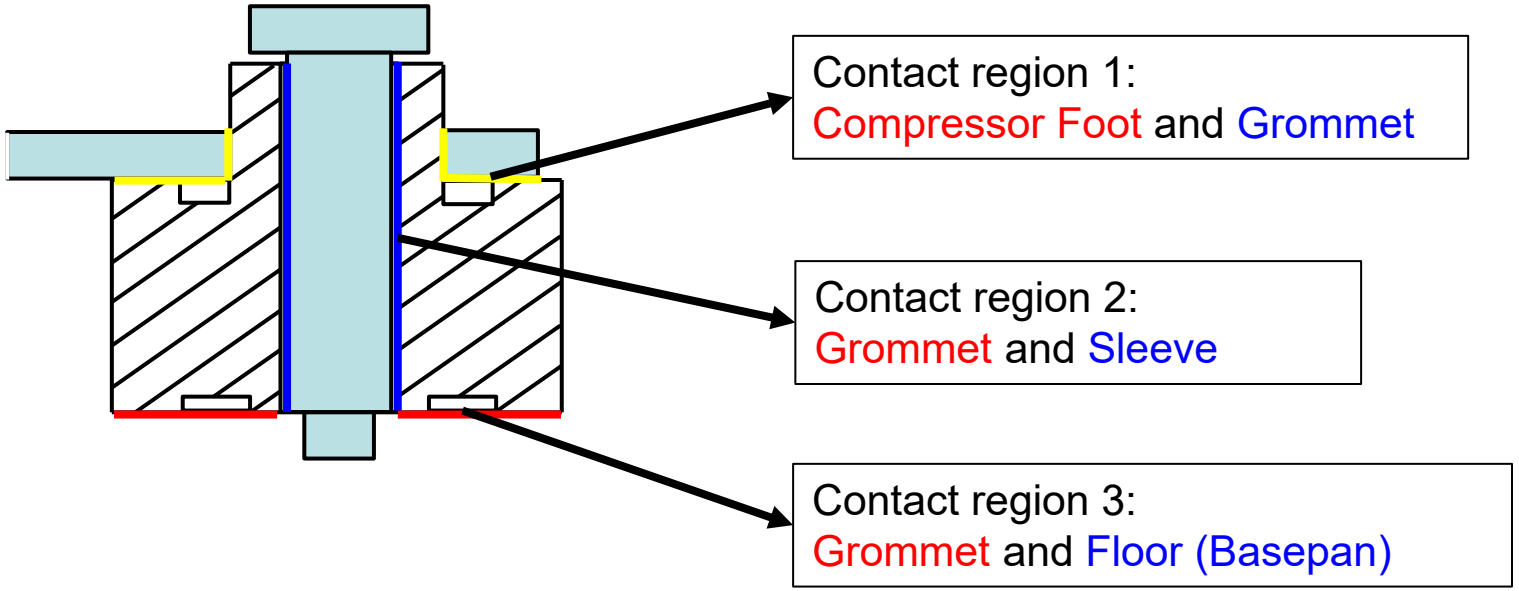
V. Jaumouillé, J.-J. Sinou, and B. Petitjean, 2012

Expected Issue Payne Effect



- Dynamic modulus is higher than the static modulus and increases with frequency.
- Dynamic modulus decreases with dynamic strain.

Expected Issue Contact



Schematic showing contact regions between compressor foot and grommet (in yellow), grommet and bolt (in blue), and between grommet and floor (in red).

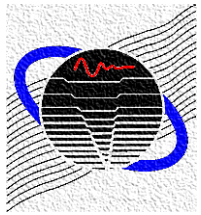
Explanation of Results

Simulated natural frequencies are compared with measurement.

For example, given that the measured natural frequency is 20 Hz and the simulated natural frequency is 15 Hz, the ratio between the two will be 0.75.

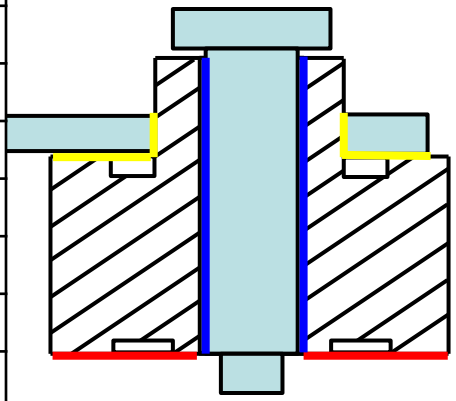
Modes were determined for 3 different compressors.

Property	Compressor 1	Compressor 2	Compressor 3
Mass (kg)	20.3	31.5	34.6



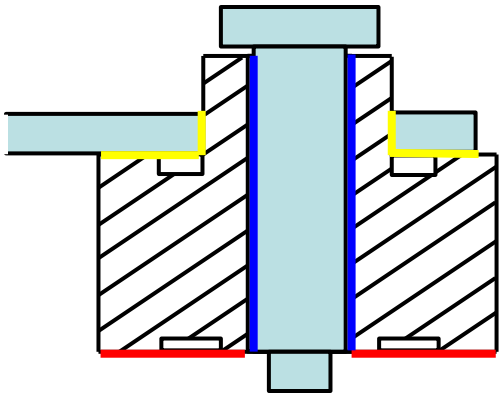
Results Boundary Condition Effect

Boundary Conditions	BC 1	BC 2	BC 3	BC 4
Yellow Contact Region	Bonded	Bonded	Frictional 0.25	Frictional 0.25
Blue Contact Region	Bonded	Frictional 0.25	Bonded	Frictional 0.25
Red Contact Region	Frictionless	Frictionless	Frictionless	Frictionless
Mode 1	0.74	0.44	0.53	0.38
Mode 2	0.74	0.45	0.53	0.39
Mode 3	0.78	0.45	0.65	0.41
Mode 4	0.79	0.52	0.44	0.47
Mode 5	0.94	0.56	0.63	0.50
Mode 6	0.94	0.56	0.63	0.50



Results Boundary Condition Effect

Boundary Conditions	BC 5	BC 6	BC 7	BC 8
Yellow Contact Region	Bonded	Bonded	Frictional 0.25	Frictional 0.25
Blue Contact Region	Bonded	Frictional 0.25	Bonded	Frictional 0.25
Red Contact Region	Fixed	Fixed	Fixed	Fixed
Mode 1	0.76	0.65	0.56	0.56
Mode 2	0.76	0.66	0.56	0.56
Mode 3	0.81	0.75	0.67	0.67
Mode 4	0.82	0.59	0.49	0.48
Mode 5	0.97	0.78	0.68	0.67
Mode 6	0.97	0.78	0.68	0.66



Results Scale Ogden Parameters

Ogden 3rd MU setting	Mode	Compare to measured results			
		Frictional Coef.			Bonded
		0.01	0.25	0.75	
×1.5	1	0.56	0.73	0.76	0.95
	2	0.57	0.74	0.76	0.95
	3	0.56	0.70	0.72	0.95
	4	0.56	0.69	0.73	0.88
	5	0.49	0.64	0.67	0.82
	6	0.50	0.64	0.67	0.82
×1.7	1	0.58	0.77	0.80	1.00
	2	0.59	0.77	0.80	1.00
	3	0.58	0.74	0.75	1.00
	4	0.59	0.74	0.78	0.93
	5	0.51	0.68	0.71	0.86
	6	0.52	0.68	0.71	0.86
×2.0	1	0.60	0.82	0.84	1.06
	2	0.63	0.82	0.84	1.07
	3	0.62	0.76	0.78	1.06
	4	0.61	0.81	0.84	1.00
	5	0.53	0.73	0.76	0.92
	6	0.54	0.73	0.76	0.92
×2.5	1	0.67	0.88	0.90	1.15
	2	0.69	0.88	0.91	1.15
	3	0.72	0.81	0.84	1.15
	4	0.66	0.89	0.92	1.11
	5	0.58	0.80	0.83	1.01
	6	0.59	0.80	0.83	1.01

Compressor model 2 results

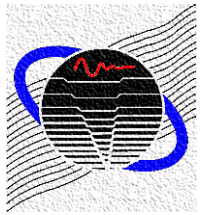
Results Scale Ogden Parameters

Ogden MU setting	Mode	Bonded (Compare to measured results)		
		Compressor 1	Compressor 2	Compressor 3
×1.5	1	0.96	1.01	0.96
	2	0.97	1.01	0.96
	3	1.06	1.03	0.85
	4	0.82	0.91	1.16
	5	0.88	0.87	0.89
	6	0.87	0.87	0.89
×1.7	1	1.01	1.05	1.00
	2	1.02	1.05	1.01
	3	1.11	1.08	0.89
	4	0.86	0.96	1.24
	5	0.92	0.92	0.93
	6	0.93	0.91	0.93
×2.0	1	1.06	1.11	1.06
	2	1.08	1.11	1.07
	3	1.18	1.14	0.94
	4	0.92	1.04	1.33
	5	0.98	0.97	1.00
	6	1.00	0.97	0.99
×2.5	1	1.15	1.19	1.16
	2	1.16	1.19	1.16
	3	1.28	1.22	1.02
	4	1.00	1.15	1.48
	5	1.07	1.06	1.09
	6	1.11	1.06	1.09

Compressor model 2 results

Summary

- The nonlinear material properties of the grommet were measured. Results were correlated with measurement and the sensitivity to material properties and boundary conditions was examined.
- Simulation results are very sensitive to the contact settings. It was found that results correlate better with measurement when the bottom surface of all contact surfaces are considered bonded but contact at the bolt sleeve is not included.
- The Ogden material model is not stiff enough due to the Payne effect. It proved best in this research to adjust the Ogden μ_1, μ_2, and μ_3 parameters by a factor between 1.5 and 2.0.
- By varying the contact settings and the Ogden parameters, acceptable agreement can be obtained. Differences are about 10% or less and they are likely similar to variations of measurements from grommet to grommet.



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