So you are given a target Radial Static Rate ?

How do I design the bushing ?

Start with Radial Rate

- **Radial Rate will vary with:**

  Bushing Geometry, Durometer and Construction

  Number of Precycles (Mullins effect)

  Cycle Strain (this is huge)

  Temperature

  Test Tooling

You need to have answers to these questions above

Construction Type

- ***You need to know how you are designing the bushing construction:***

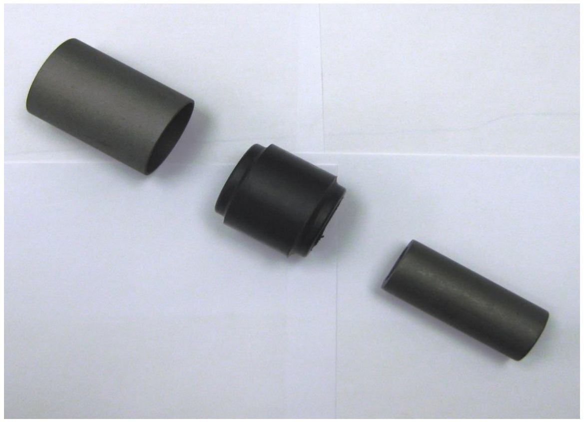
  ie: mold bonded and swaged

  or: 3 piece or center joint bonded

  and shot together

- ***For this example we will pick Mold Bonded and swged after molding***

Bushing Construction



3 Piece

Center Joint Bonded

Mold Bonded and swaged

Durometer and Compression Amount

- ***Durometer will guide us toward Shear Modulus G (psi)   Most bushings 55 – 65 Shore A***

- ***Also need to know amount of compression***

  Swaged Bushing ~ 3 – 5 %

  Shot Bushing ~ 20 – 30 %

- ***Also the amount of expected deflection for the modulus determination. Don't know guess 20%***

Shear Modulus G (psi) cont.

- *You will want to pick a Shear Modulus next*
- *Start design at 60 durometer using 20% static deflection and 5 % swaged design.*
- *Pick a Shear Modulus =* **150 psi for 60 duro.**

NR Material Properties

reference 4

Shear Modulus psi	Youngs Modulus psi	Bulk Modulus psi	Durometer Shore A
43	130	142	30
53	168	142	35
64	213	142	40
76	256	142	45
90	310	146	50
115	460	154	55
150	630	163	60
195	830	171	65
245	1040	180	70
317	1340	189	75

G = Shear Modulus

E = Young’s Modulus

B = Bulk Modulus

Conversions:

1 psi = 0.00689 MN/m²

1 kg/cm² = 0.0981 MN/m²

1 N/m² = 1 Pa (Pascal)

1 MN/m² = 1 MPa

Bushing Geometry Details

D = Outer Metal Inside Diameter (in)

d = Inner Metal Outside Diameter (in)

r_2 = Outer Metal Inside Radius (in)

r_1 = Inner Metal Outside Radius (in)

L = Rubber Length (in)

G = Rubber Shear Modulus (psi=lbs/in^2)

Si = Shape Constant (unitless)

Bushing Formula Summary Conventional (English Units)

Kr = radial static rate

$$\mathrm{Kr} = \frac{7.5(\pi)(L)(G)}{\ln\left(\frac{r^{2}}{r^{1}}\right)} \quad (Si)$$

Equation 1 (Freakley)

$$Si = 1 + \quad \frac{0.0097\left(L^{3}\right)}{\left(\frac{r^{2}}{r^{1}}\right)^{3}}$$

Equation 2 (Freakley)

Bushing Formula Summary Conventional (English Units)

Ka= axial static rate

$$\mathrm{Ka} = \frac{2.73(G)(L)}{\log^{10}\left(\frac{D}{d}\right)}$$

Equation 3 (Gent)

Bushing Formula Summary Conventional (English Units)

Kt= torsional static rate

$$Kt = \frac{0.055(G)(L)}{\frac{1}{d^2} - \frac{1}{D^2}} \qquad \text{(degrees)}$$

Equation 4 (Gent)

Bushing Formula Summary
Conventional (English Units)

Kc= conical static rate

$$\text{Kc} = \frac{N(\pi)(L^3)(G)(X^2+1)}{(X^2+1)\ln(X) - (X^2-1)}\ (0.0174)$$

N = constant

$$\text{X} = \frac{r^2}{r^1}$$

Equation 5 (Payne & Scott)

Notes on Static Rate Equations

- ***There are many equations for static rates***

I will show others in the class notes

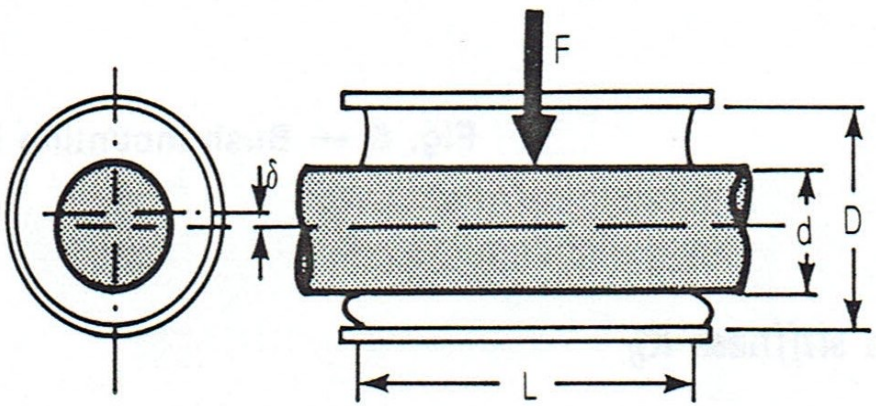
- ***For Conical the N value will be shown from experimental values***

- ***For Conical end units will be Torque per degree***

Now lets choose some bushing dimensions

(It's always best if you have some past data to compare to when choosing bushing geometry)

Bushing Static Rate Calculation Example



Example Rubber Section

D = Outer Dia = 2.22 in

r_2 = 1.11 in

d = Inner Dia = 1.43 in

r_1 = 0.715 in

L = Length = 2.378 in

Duro ~ 60 Shore A

G = 150 psi

G is from chart or determined experimentally

Radial Rate Kr Stiffness Equations

$$\mathrm{Kr} = \frac{7.5(\pi)(L)(G)}{\ln\left(\frac{r^2}{r^1}\right)} \ (Si)$$

Equation 1 (Freakley)

$$Si = 1 + \frac{0.0097\left(L^3\right)}{\left(\frac{r^2}{r^1}\right)^3}$$

Equation 2 (Freakley)

- ***So you will need to estimate :***
- ***L = Length of Bushing***
- ***r^2 = Inner Radius Outer Metal***
- ***r^1 = Outer radius Inner Metal***

Substitute into Radial Stiffness Equations

$$Si = 1 + \frac{0.0097\left(L^3\right)}{\left(\frac{r2}{r1}\right)^3}$$

$$Si = 1 + \frac{0.0097(2.378^3)}{\left(\frac{1.11}{0.715}\right)^3}$$

$$Si = 3.12$$

Substitute into Radial Stiffness Equations

$$\mathrm{Kr} = \frac{7.5(\pi)(L)(G)}{\ln\left(\frac{r^2}{r^1}\right)} \quad (Si)$$

$$\mathrm{Kr} = \frac{7.5(3.14)(2.378)(150)}{\ln\left(\frac{1.11}{0.715}\right)} \quad (3.12)$$

$$\mathrm{Kr} = 59550 \text{ lb/in}$$

I calculated Static Rates for this bushing in four directions

- ***I used equations from Freakley ,Gent, Payne***
- ***I also had a part that I measured Kr in the lab***
- ***I had a colleauge run FEA and have those results as well***

Bushing Rate Calculations vs Real vs FEA

	Calculated		Experimental	
	Freakley	Gent	Actual Part	FEA
Kr (lbs/in)	59550	58856	57400	54578
Ka (lbs/in)		5100		4391
Kt (in-lbs/deg)		67.5		61
Kc (in-lbs/deg)		253		228

It seems easy, but its not

- ***In the sections available in this website I will discuss:***
- ***How shear modulus G changes based on durometer, the amount of precompression in the rubber wall and the amount of strain put into the rubber bushing.***
- ***Other equations for calculating Static Rates***
- ***How to run laboratory tests and get the accurate static rates***
- ***Effects of temperature on natural rubber bushings***
- ***Fatigue Life***
- ***Many actual examples listed by size and rubber static rates***

References for Bushing Static Rate Calculations

1) **Adkins, J.E. and Gent, A.N. (1954)** ***British Journal of Applied Physics*** **5, 354*.***

2) ***Freakley, P.K. and Payne, Theory and Practice of Engineering with Rubber Applied Science Publishers Ltd. London pgs 174 (1978)***

3) ***Payne A.R and Scott J.R., Engineering Design with Rubber MacLauren & Sons pg 158 (1960)***

4) ***Lindley, P.B., Engineering Design with Natural Rubber , NRPRA pg. 8***