The following are the design equations for the simplest possible model of the magnetic circuit found inside a voice coil actuator. It is a flux loop with two reluctances (the magnetic equivalent of a resistor). The first reluctance is that of the magnet and the second is the air gap that separates the “flux puck” from the stator walls. The magnetic equivalent of the wire which connects these two reluctances is the iron of the stator and the flux puck.

The design of the actuator begins with a choice of required force, F, and displacement, Δ along with a magnet. For this example, consider a desired force of 111 N with 1 mm of throw and a Neodynium-Iron-Boron magnet that is 50 mm in diameter and 20 mm thick.

The simpleminded approach here optimizes the design of the actuator by forcing the reluctance of the air gap to be equal to that of the magnet. Hence, the width of the air gap is:

$$w_{gap} = \frac{t_{mag} A_{gap}}{A_{mag}/mumag} \tag{1}$$

$$A_{gap} = \pi d_{mag} h_{gap} \tag{2}$$

$$A_{mag} = \pi \left(\frac{d_{mag}}{2}\right)^2 \tag{3}$$

where t_{mag} is thickness of magnet, d_{mag} is the magnet diameter, h_{gap} is the gap height and μ_{mag} is relative permeability of the magnetic material (1.05 for NdFeB). For the specifications given above and a gap height of 10 mm, the gap width is 15 mm.

Given a gap width, w_{gap}, the horizontal and vertical room for turns of wire is:

$$w_{wire} = w_{gap} - (t_{bob} + 2w_{clear}) \tag{4}$$

$$h_{wire} = h_{gap} + 2\Delta \tag{5}$$

where t_{bob} is the bobbin wall thickness (1.5 mm) and w_{clear} is the bobbin clearance (1.0 mm). The resulting width and height for wire is 11.7 mm x 12 mm.

Now that the air gap and wire area have been defined, it remains to determine the magnetic flux density of the air gap and how much electrical current must be run through that gap to create the requisite force. The equivalent strength of the magnet is given by:

$$\Psi_{mag} = H_r t_{mag} \tag{6}$$

where H_r is the remanence of the magnetic material (about 10500 Oersted for NdFeB). The total reluctance of the circuit is:

$$\Gamma = \frac{w_{gap}}{A_{gap}\mu_0} + \frac{t_{mag}}{A_{mag}\mu_0\mu_{mag}} \tag{7}$$

The calculated reluctance for this example is 1.54 X 10^7 henry^{-1}. The flux density in the gap is:

$$\Phi_{gap} = \frac{\Psi_{mag}}{\Gamma} \tag{8}$$

Finally, the flux in the gap is:

$$B = \frac{\Phi_{gap}}{A_{gap}} \tag{9}$$

and for this example, the flux in the gap is 0.69 tesla. Given this flux, the coil must produce:

$$Ni_{req} = \frac{F}{B} \tag{10}$$

which for this example is 160.7 m·A. So, this means that we need 160.7 meters of wire at 1 amp, or somewhat more current for a shorter length of wire.

To determine which wire to use, we choose a packing factor, how tight the turns are going to be wound (say, $k_p = 0.8$). For this example, consider 24 guage wire with a diameter of d =0.5 mm and a resistivity of ρ =0.092 ohm/m. The number of turns are:

$$turns = k_p \left(\frac{w_{wire} h_{wire}}{(d/2)^2 \pi}\right) \tag{11}$$

The length of wire and resistance in the wire is:

$$l = turns\left(2\pi\left(\frac{d_{mag}}{2} + w_{gap} - w_{clear}\right)\right) \tag{12}$$

$$R = \rho l \tag{13}$$

The current in the wire is:

$$i = \frac{N i_{req}}{2\pi k_p \frac{h_{gap} w_{wire}}{(d/2)^2 \pi} (d_{mag}/2 + w_{gap} - w_{clear})} \tag{14}$$

which comes out to 1.8 A at 22.5 V. Repeat as much as necessary to find the current and voltage that match your amplifier (I used the Pa26 from Apex) and will not burn up the wire (this is a little high current for 24 guage).

Finally, design the stator thickness to be sufficient enough as to avoiding magnetic flux saturation:

$$t_{stator} = \sqrt{\frac{\Phi_{gap}}{B_{max}} + \left(\frac{d_{mag} + 2w_{gap}}{2}\right)^2} - \left(\frac{d_{mag} + 2w_{gap}}{2}\right) \tag{15}$$

which is 8.4 mm for a maximum saturating flux in iron of 1.45 tesla.