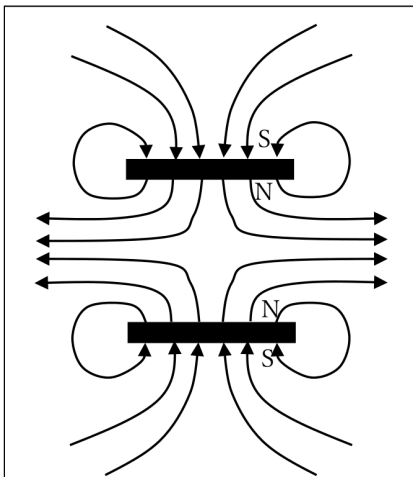
질량 측정

파트 A: 훅의 법칙과 전자기력 (2.4점)

A.1 (0.4pt)

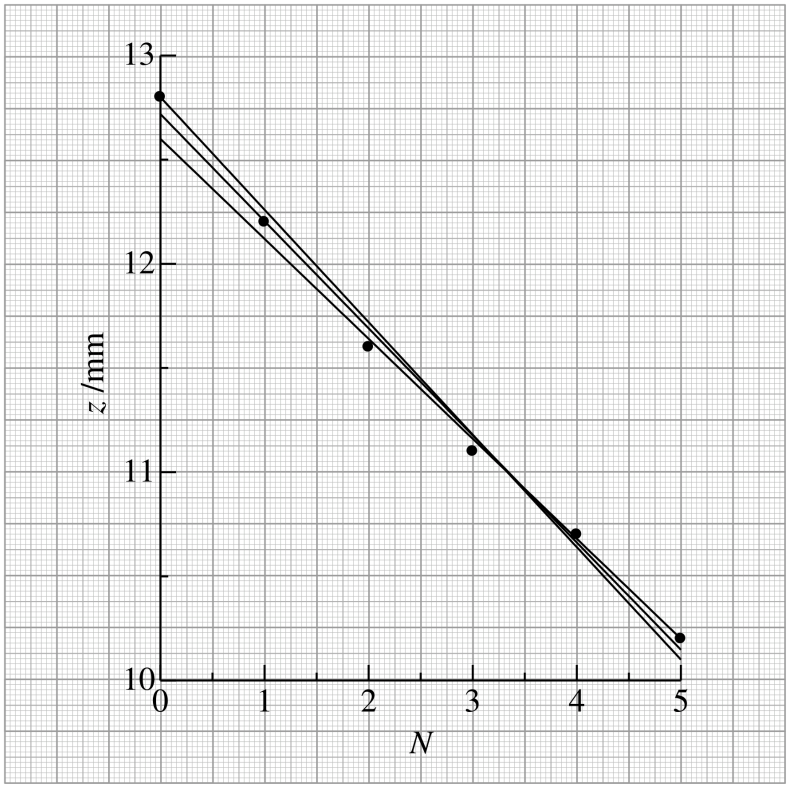


A.2 (0.6pt)

N	z /mm	I /A
0	12.8	0
1	12.2	0.103
2	11.6	0.213
3	11.1	0.323
4	10.7	0.423
5	10.2	0.524

A.3 (0.7pt)

A.3 (0.7 pt)



The slope and uncertainty are read from the lines plotted on the graph.

$$a = \frac{\Delta z}{\Delta N} = \frac{10.15 - 12.70}{5} = -0.51$$

$$a_+ = \frac{10.20 - 12.60}{5} = -0.48$$

$$a_- = \frac{10.10 - 12.80}{5} = -0.54$$

$$\Delta a = \frac{-0.48 - (-0.54)}{2} = 0.03$$

$$a = -0.51 \pm 0.03 \text{ mm}$$

$$a = \frac{\Delta z}{\Delta N} = \frac{10.15 - 12.70}{5} = -0.51$$

$$a_+ = \frac{10.20 - 12.60}{5} = -0.48$$

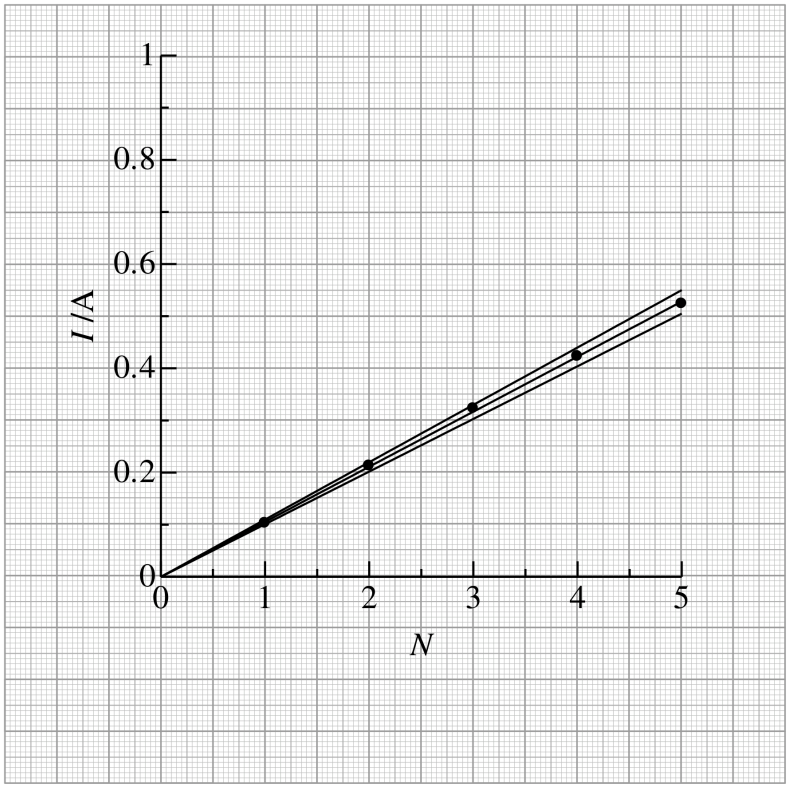
$$a_- = \frac{10.10 - 12.80}{5} = -0.54$$

$$\Delta a = \frac{-0.48 - (-0.54)}{2} = 0.03$$

$$a = -0.51 \pm 0.03 \text{ mm}$$

A.4 (0.7pt)

A.4 (0.7 pt)



The slope and uncertainty are read from the lines plotted on the graph.

$b = \frac{I}{N} = \frac{0.53}{5} = 0.106$

$b_+ = \frac{0.55}{5} = 0.110$

$b_- = \frac{0.505}{5} = 0.101$

$\Delta b = \frac{0.110 - 0.101}{2} = 0.005$

$b = 0.106 \pm 0.005$ A

$$b = \frac{I}{N} = \frac{0.53}{5} = 0.106$$

$$b_+ = \frac{0.55}{5} = 0.110$$

$$b_- = \frac{0.505}{5} = 0.101$$

$$\Delta b = \frac{0.110 - 0.101}{2} = 0.005$$

$$b = 0.106 \pm 0.005 \text{ A}$$

파트 B: 유도 기전력 (3.0점)

B.1 (0.2pt)

$V = 2\pi f A B L$

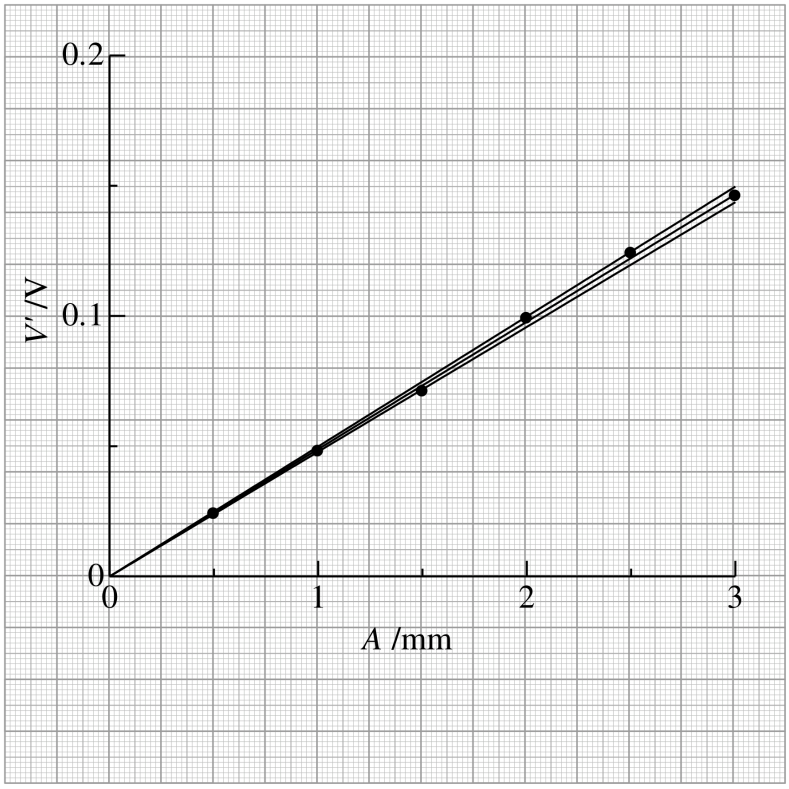
B.2 (0.5pt)

$f_B = 15.85\ \mathrm{Hz}$

A /mm	V' /V
0.5	0.024
1.0	0.048
1.5	0.071
2.0	0.099
2.5	0.124
3.0	0.146

B.3 (0.7pt)

B.3 (0.7 pt)



The slope and uncertainty are read from the lines plotted on the graph.

$c = \frac{V'}{N} = \frac{0.147}{5} = 0.049$

$c_+ = \frac{0.150}{5} = 0.050$

$c_- = \frac{0.144}{5} = 0.048$

$\Delta c = \frac{0.050 - 0.048}{2} = 0.001$

$c = 0.049 \pm 0.001\ \mathrm{V/mm}$

$$c = \frac{V'}{A} = \frac{0.147}{5} = 0.049\ \mathrm{V/mm}$$

$$c_+ = \frac{0.150}{5} = 0.050, \quad c_- = \frac{0.144}{5} = 0.048$$

$$\Delta c = \frac{0.050 - 0.048}{2} = 0.001\ \mathrm{V/mm}$$

$$c = 0.049 \pm 0.001\ \mathrm{V/mm}$$

B.4 (0.4pt)

$$BL = \frac{V}{2\pi A f_B}, \quad V' = V/\sqrt{2}$$

$$BL = \frac{\sqrt{2}\,V'}{2\pi A f_B} = \frac{\sqrt{2}\,c}{2\pi f_B} = \frac{\sqrt{2}\times 0.049}{2\pi \times 15.85} = 0.000696\ \mathrm{Vs/mm} = 0.696\ \mathrm{Vs/m}$$

$$\Delta(BL) = \frac{\sqrt{2}\,\Delta c}{2\pi f_B} = \frac{\sqrt{2}\times 0.001}{2\pi \times 15.85} = 0.000014\ \mathrm{Vs/mm} = 0.014\ \mathrm{Vs/m}$$

$$BL = 0.696 \pm 0.014\ \mathrm{Vs/m}$$

B.5 (1.2pt)

$$m = BL \cdot \frac{I}{g} = \frac{BL}{g} \cdot \frac{I}{N} = \frac{BL\,b}{g} = \frac{0.696\times 0.106}{9.80} = 0.0075\ \mathrm{kg} = 7.5\ \mathrm{g}$$

$$\Delta m = \sqrt{(\Delta b)^2\left(\frac{BL}{g}\right)^2 + \left(\frac{b}{g}\right)^2(\Delta(BL))^2} = 0.00039\ \mathrm{kg} = 0.4\ \mathrm{g}$$

$$m = 7.5 \pm 0.4\ \mathrm{g}$$

$$k = -\frac{mg}{a} = -\frac{0.0075\times 9.80}{-0.51} = 0.144\ \mathrm{N/mm} = 144\ \mathrm{N/m}$$

$$\Delta k = \sqrt{(\Delta a)^2\left(\frac{mg}{a^2}\right)^2 + \left(\frac{g}{a}\right)^2(\Delta m)^2} = 0.011\ \mathrm{N/mm} = 11\ \mathrm{N/m}$$

$$k = 144 \pm 11\ \mathrm{N/m}$$

$$\left(\Delta m = \left|\frac{BL}{g}\right|\Delta b + \left|\frac{b}{g}\right|\Delta(BL), \quad \frac{\Delta m}{m} = \frac{\Delta b}{b} + \frac{\Delta(BL)}{BL}, \quad \frac{\Delta m}{m} = \sqrt{\left(\frac{\Delta b}{b}\right)^2 + \left(\frac{\Delta(BL)}{BL}\right)^2}\ \text{도 인정}\right)$$

$$\left(\Delta k = \left|\frac{mg}{a^2}\right|\Delta a + \left|\frac{g}{a}\right|\Delta m, \quad \frac{\Delta k}{k} = \frac{\Delta a}{|a|} + \frac{\Delta m}{m}, \quad \frac{\Delta k}{k} = \sqrt{\left(\frac{\Delta a}{a}\right)^2 + \left(\frac{\Delta m}{m}\right)^2}\ \text{도 인정}\right)$$

파트 C. 질량에 따른 공명 진동수 (2.3점)

C.1 (0.2pt)

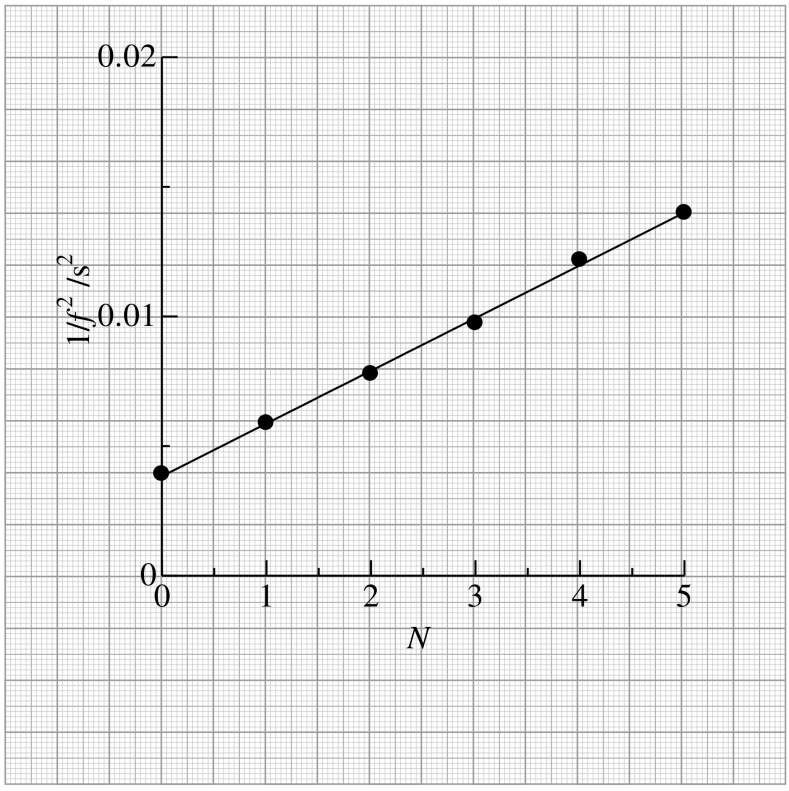
$$f_N = \frac{1}{2\pi}\sqrt{\frac{k'}{M+Nm}}$$

C.2 (0.5pt)

N	f /Hz	$1/f^2$ /s^2
0	15.96	0.003926
1	13.03	0.005390
2	11.33	0.007790
3	10.13	0.009745
4	9.06	0.01218
5	8.45	0.01401

C.3 (1.0pt)

C.3 (1.0 pt)



The additional quantities $1/f^2$ are calculated in Table C.2. Then, $\frac{M}{k'}$ and $\frac{m}{k'}$ are obtained from the graph using the equation $\frac{1}{f^2} = (2\pi)^2(\frac{M}{k'} + \frac{m}{k'}N)$.

$$\frac{M}{k'} = \frac{0.0039}{(2\pi)^2} = 9.88 \times 10^{-5}\ \mathrm{s}^2$$

$$\frac{m}{k'} = \frac{(0.0140 - 0.0039)/5}{(2\pi)^2} = 5.12 \times 10^{-5}\ \mathrm{s}^2$$

식 $\frac{1}{f^2} = (2\pi)^2\left(\frac{M}{k'} + \frac{m}{k'}N\right)$ 을 이용하여 그래프에서 $\frac{m}{k'}$ 과 $\frac{M}{k'}$ 을 얻는다.

$$\frac{M}{k'} = \frac{1/f_0^2}{(2\pi)^2} = \frac{0.0039}{(2\pi)^2} = 9.88 \times 10^{-5}\ \mathrm{s}^2$$

$$\frac{m}{k'} = \frac{(0.0140 - 0.0039)/5}{(2\pi)^2} = \frac{0.00202}{(2\pi)^2} = 5.12 \times 10^{-5}\ \mathrm{s}^2$$

C.4 (0.6pt)

$$\frac{M}{m} = \frac{M/k'}{m/k'} = \frac{9.88}{5.12}$$

$$\frac{M}{m} = 1.93$$

$$M = \frac{M}{m} \cdot m = 1.93 \times 0.0075 = 0.0145\ \mathrm{kg} = 14.5\ \mathrm{g}$$

$$M = 14.5\ \mathrm{g}$$

$$k' = \frac{M}{M/k'} = \frac{0.0145}{9.88 \times 10^{-5}}$$

$$k' = 147\ \mathrm{N/m}$$

파트 D. 공명 특성 (2.3점)

D.1 (0.4pt)

$V'_{AC} = 0.157\ \mathrm{V}$

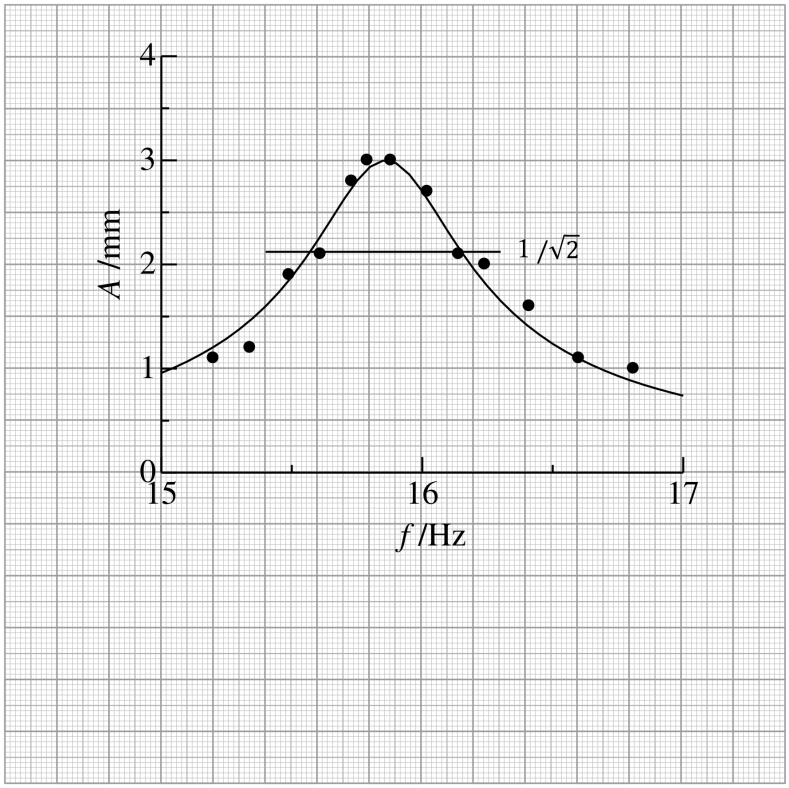
$F_{AC} = BL\, I_{AC} = BL \times 0.106 \times \sqrt{2}\, V'_{AC} = 0.696 \times 0.106 \times \sqrt{2} \times 0.157 = 0.0164\ \mathrm{N}$

D.2 (0.9pt)

f /Hz	A /mm
15.88	3.0
15.79	3.0
15.73	2.8
15.61	2.1
15.49	1.9
15.34	1.2
15.20	1.1
16.02	2.7
16.14	2.1
16.24	2.0
16.41	1.6
16.60	1.1
16.81	1.0

D.2 (계속)

D.2 (cont.)



D.3 (1.0pt)

그래프 D.2에서 읽음

$f_0 = 15.83\ \text{Hz}$

$A(f_0) = 3.0\ \text{mm}$

$$\Delta f = \frac{16.14 - 15.56}{2} = 0.29\ \text{Hz}$$

식 (4)를 이용한 계산

$$M = \frac{F_{AC}}{8\pi^2 f_0\, \Delta f\, A(f_0)} = \frac{0.0164}{8\pi^2 \times 15.83 \times 0.29 \times 0.003} = 0.0151\ \text{kg} = 15.1\ \text{g}$$

$M = 15.1\ \text{g}$