As an engineer for Coffeepots, Ltd., you are responsible for the mechanism which keeps the coffee hot. One day your manager comes to you and tells you that he wants you to build a control system that will allow coffee to stay close to a temperature specified by the consumer. Before you start making the compensator, you take some data on the frequency response of the coffee pot $G_p(j\omega)$. This data is given in the table on the next page.

Upon seeing this data, you decide that you would like to shoot for a phase margin of $\phi_M = 30^\circ$ in a feedback system configured as in the figure above. Now that your problem is well defined, you need to decide upon a compensator. Since the company hasn’t bought you a computer yet, you resolve to work out the design for the compensator by hand. You aren’t sure which type of compensator will be best suited for the job, however, so you try a couple of designs.

Specify the transfer functions for the following compensator $G_c(s)$ so that bandwidth is maximized and steady-state error is minimized for the heat in your coffeepot:

(a) A reduced gain compensator

$$G_c(s) = K_R$$

(b) A lag compensator

$$G_c(s) = \frac{\tau s + 1}{\alpha\tau s + 1}$$

(c) A lead compensator

$$G_c(s) = K_L \left( \frac{10\tau s + 1}{\tau s + 1} \right)$$
Coffee Pot Data:

$$\omega \quad |G_p(j\omega)| \quad \angle G_p(j\omega)$$

| \omega (\text{rad/s}) | |G_p(j\omega)| \quad \angle G_p(j\omega) |
|-------------------------|--------------------------|--------------------------|
| 1.000e+001              | 6.325e+002               | -135.74                  |
| 1.151e+001              | 5.119e+002               | -135.86                  |
| 1.326e+001              | 4.143e+002               | -135.99                  |
| 1.526e+001              | 3.354e+002               | -136.14                  |
| 1.758e+001              | 2.714e+002               | -136.31                  |
| 2.024e+001              | 2.197e+002               | -136.51                  |
| 2.330e+001              | 1.778e+002               | -136.74                  |
| 2.683e+001              | 1.439e+002               | -137.00                  |
| 3.089e+001              | 1.165e+002               | -137.30                  |
| 3.556e+001              | 9.430e+001               | -137.65                  |
| 4.095e+001              | 7.632e+001               | -138.05                  |
| 4.715e+001              | 6.178e+001               | -138.51                  |
| 5.429e+001              | 5.000e+001               | -139.04                  |
| 6.251e+001              | 4.047e+001               | -139.66                  |
| 7.197e+001              | 3.276e+001               | -140.36                  |
| 8.286e+001              | 2.651e+001               | -141.17                  |
| 9.541e+001              | 2.146e+001               | -142.11                  |
| 1.099e+002              | 1.737e+001               | -143.18                  |
| 1.265e+002              | 1.406e+001               | -144.42                  |
| 1.456e+002              | 1.138e+001               | -145.85                  |
| 1.677e+002              | 9.211e+000               | -147.49                  |
| 1.931e+002              | 7.455e+000               | -149.38                  |
| 2.223e+002              | 6.034e+000               | -151.56                  |
| 2.560e+002              | 4.884e+000               | -154.06                  |
| 2.947e+002              | 3.953e+000               | -156.95                  |
| 3.393e+002              | 3.200e+000               | -160.27                  |
| 3.907e+002              | 2.590e+000               | -164.10                  |
| 4.498e+002              | 2.096e+000               | -168.51                  |
| 5.179e+002              | 1.697e+000               | -173.58                  |
| 5.964e+002              | 1.373e+000               | -179.42                  |
| 6.866e+002              | 1.112e+000               | -186.14                  |
| 7.906e+002              | 8.997e-001               | -193.89                  |
| 9.103e+002              | 7.282e-001               | -202.80                  |
| 1.048e+003              | 5.894e-001               | -213.07                  |
| 1.207e+003              | 4.771e-001               | -224.89                  |
| 1.389e+003              | 3.861e-001               | -238.50                  |
| 1.600e+003              | 3.125e-001               | -254.16                  |
| 1.842e+003              | 2.530e-001               | -272.21                  |
| 2.121e+003              | 2.048e-001               | -292.98                  |
| 2.442e+003              | 1.657e-001               | -316.90                  |
| 2.812e+003              | 1.341e-001               | -344.43                  |
| 3.237e+003              | 1.086e-001               | -376.14                  |
| 3.728e+003              | 8.788e-002               | -412.65                  |
| 4.292e+003              | 7.113e-002               | -454.68                  |
| 4.942e+003              | 5.757e-002               | -503.08                  |
| 5.690e+003              | 4.660e-002               | -558.81                  |
| 6.551e+003              | 3.772e-002               | -622.97                  |
| 7.543e+003              | 3.053e-002               | -696.85                  |
| 8.685e+003              | 2.471e-002               | -781.91                  |
| 1.000e+004              | 2.000e-002               | -879.85                  |