January 1997

Doctoral Qualifying Examination

System Dynamics & Control

Oral Examination

Monday, January 27th, 1997

The accompanying figure is based on a cross-sectional drawing of a pressure regulator for a vacuum source for dental and medical applications. (The kind of machine used to suck fluid out of your mouth when you’re having dental work done.)

The problem:

A scaled-up version of a presently-working design exhibits “instability” in the form of (unacceptable) sustained oscillations of chamber pressure.

Your task:

Develop a mathematical model and analysis to explain (1) the origin of the instability and (2) how it might be eliminated.

How the device is supposed to work:

An increase of vacuum pump pressure ($P_{\text{low}}$) would tend to reduce the outgoing flow rate. For a constant incoming flow rate, that would cause the chamber pressure to rise and move the diaphragm in the direction to open the valve, thereby reducing the increase of chamber pressure. (A decrease of vacuum pump pressure would have the converse effect.)

A decrease of incoming flow rate ($Q_{\text{in}}$) would tend to reduce the chamber pressure and move the diaphragm in the direction to close the valve, thereby offsetting the reduction of chamber pressure.

Some guidance:

The pressure oscillations occur at sufficiently high frequencies that any thermal effects (e.g., heat transfer) are likely to be negligible.

Because the moving part of the valve is mounted on a flexible diaphragm, mechanical friction is likely to be negligibly small.

For small motions about equilibrium, the diaphragm is extremely compliant. You may find it useful to neglect the diaphragm stiffness.

To keep things clear and simple, you should consider linearizing any nonlinear equations and analyzing the linearized dynamic equations.