ECE 147C / ME 106A

Spring 2007

Laboratory #2

Empirical Introduction to Rijke Tube

In this experiment we will operate the Rijke Tube and try to control it using a microphone sensor and a speaker actuator empirically. In this portion of the experiment, no mathematical modeling of the system is attempted, rather a simple minded negative proportional feedback scheme is used to see whether the sustained acoustical oscillations in the Rijke Tube can be eliminated by acoustic feedback. This is a nice illustration of how by the use of feedback, one can sometimes bypass the modeling process of a rather complex system.

Figure 1 shows a schematic diagram of the Rijke Tube control system. The coil is heated by sending a current through it using a power supply set in the range of 300-400W. The coil causes heated air to rise within the glass tube, creating a standing acoustic wave. The acoustic wave has a sinusoidal profile with a frequency of approximately 140 Hz. The loud roar of the acoustic wave is measured by a microphone and pre-amplified with a fixed gain of 7.5 V/V and a bandwidth of 1 kHz. The output from the pre-amplifier is a scaled version of **d** and is denoted by **x.** The signal **x** is sent through a variable amplifier that has a gain $\mathbf{K_A}$ that can be varied between $K_A = 0$ and $K_A = 1$ using the "MIC GAIN" knob. The variable amplifier can be viewed as a proportional sensor that outputs $\mathbf{y = K_A x}$.

For implementation of feedback control, the sensor output **y** can be sent to an analog controller that outputs some control signal **u**. The control signal **u** is amplified by a power amplifier that has a gain of 10 V/V. The output **w** from the power amplifier is sent to a speaker. The speaker outputs a sound wave which can be considered as the input to the Rijke Tube.

Your objective in this experiment is to first demonstrate that this simple negative feedback scheme works. The main part of this experiment is to figure out how the amplifier is connected to the microphone and speaker and how to implement this scheme. A full understanding of the amplifier circuitry is required. This will be given in a separate handout.

The fixed pre-amplifier, variable amplifier, and power amplifier are all housed within the "Audio Amplifier" chassis that is powered using a +/- 15V power supply. The Audio amplifier contains a "DAS" switch that can be set to "OUT" or "IN". In the "OUT" position, sensor output **y** is internally connected directly to the power amplifier (**u = y)**. In the "IN" position, sensor output **y** is internally decoupled from **u**, which enables the implementation of external feedback control.

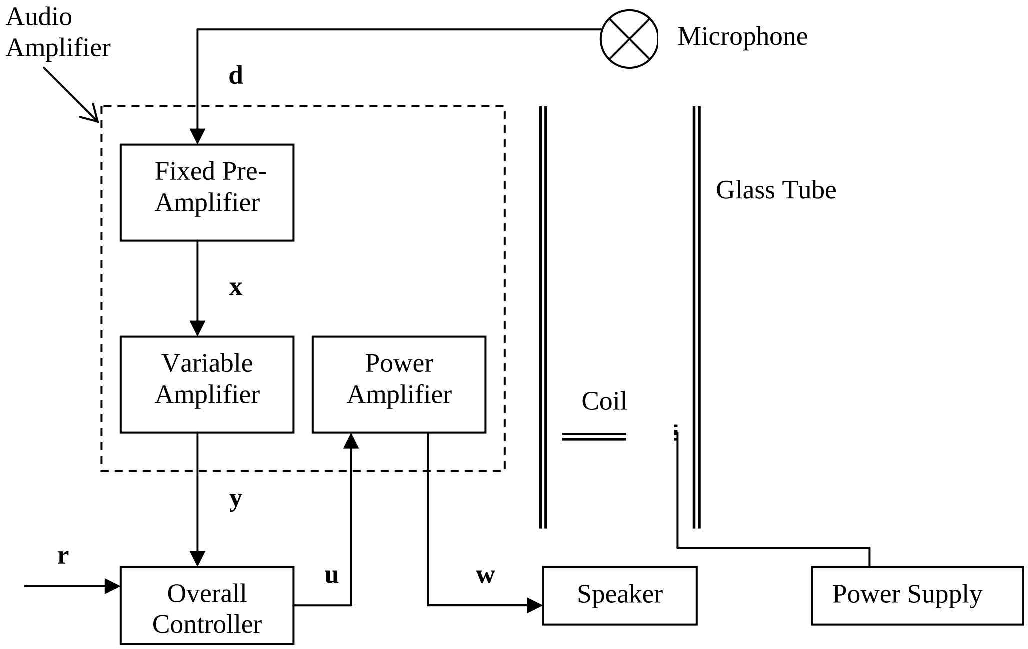


Figure 1: Rijke tube apparatus

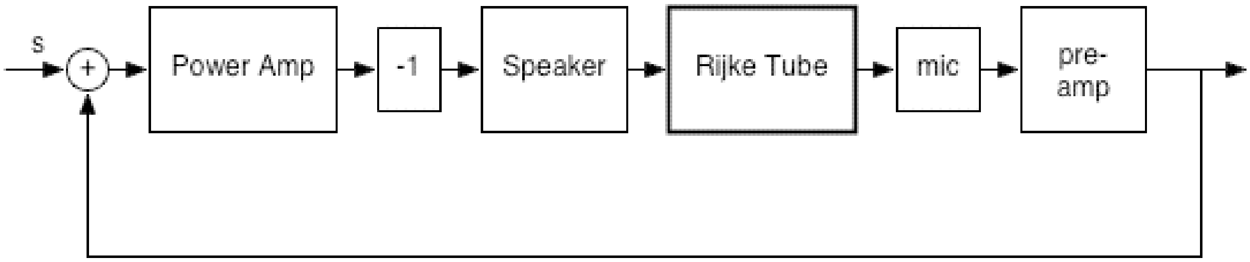
Investigation of Rijke Tube and Sensor Output

Turn on the power supplies to the heating coil and hear the loud roar. Note that for any change of the power to the heating coil, it takes the system about 10 seconds to reach steady state. Keep this in mind while you change the power to the heating coil. Make sure that the coil does not overheat (i.e. use the as little power as possible to get a reasonable acoustic oscillation in the tube), otherwise it will be damaged.

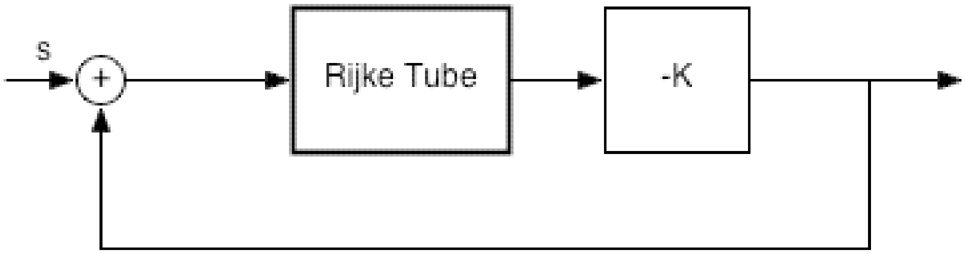
1. Without any feedback control, view the output of the microphone (through the preamp) on an oscilloscope. Note that the signal is a rather clean sinusoid, i.e. it appears to have no harmonics. Note the frequency.
2. To provide negative feedback, use either an external op-amp circuit to obtain a –1 gain, or flip the connections on the speaker (the initial connections on the speaker are set for positive feedback, but depending on when you do this experiment, those connections might be altered, make sure you check the amplifier circuit diagram and the speaker connections to understand how you might be providing positive or negative feedback). Note that for some range of negative feedback gains, the loud roar will disappear.
   Measure and observe the speaker output by measuring the signal into the speaker. *Observe how the speaker output decays to zero as the gain is increased just enough to eliminate the roar.*
3. Keep increasing the gain until the tube begins to resonate again. Measure the output signal and note its frequency. It should a some harmonic of the original loud roar.

Nonparametric Identification of Rijke Tube Frequency Response

In this part you will perform frequency response measurements on the Rijke Tube while it is being stabilized by proportional feedback. The diagram for the system is shown in the Figure below.



The Rijke Tube block is the dynamics that we would like to identify. Without feedback, these are unstable and undergo a limit cycle (the oscillation you hear). When the Rijke Tube block is stabilized by feedback, only it's linear part is active, and we can thus regard this block as approximately a linear time invariant system given by some transfer function G(s) (note that this transfer function is probably unstable or marginally stable). For the purposes of this experiment, we can regard the Power Amp, the Speaker, the Microphone and the Pre-Amp as ideal devices that have a flat frequency response, i.e. we will consider them as proportional gains. Multiplying all these gains together into a single constant -K, the above diagram can be redrawn as



The signal S in the above diagram is an interrogation signal that we will use to excite the system with sinusoids in order to identify it. This signal will come from the "source" output of the Dynamic Signal Analyzer. If K is chosen so that the system is stable, then we can identify the closed loop transfer function from S to the pre-amp output. Call this closed loop transfer function T(s), we then have

$$T(s) = -G(s)K / (1+G(s) K),$$

Which when solved for G(s) gives

$$G(s) = -T(s) / (1+T(s)) K .$$

Thus, G can be found from T and vice versa.

1. **Closed loop frequency response of the Rijke Tube**

   Connect the DAC board to the feedback circuits of the Tube as shown in the diagram above. Make sure that the source signal goes into a high impedance load (the resistor in the op-amp circuit that implements the summing junction). First stabilize the Rijke Tube with a certain feedback gain K and then measure the closed loop frequency response for the following two choices of the gain K.

   A. Choose K so that it is just higher than what is needed to stabilize the first fundamental mode of the tube.
   B. Choose K so that it is just below the gain that causes the second (higher frequency) instability to occur.

Collect time series data on both the inputs and outputs. Collect enough data to be able to achieve reliable frequency response identification (you may have to experiment a little to find out how much data is enough).

2. Analysis

Use the identification toolbox frequency response estimation routines on the data you collected to find a reliable frequency response plot for both instances of the closed loop system. Decide on the number of poles you will need to fit a pole/zero transfer function model for the closed loop. Compute the corresponding open loop model. They should be the same in both cases.

Rijke Tube Laboratory Report

The main sections should include:

1. Plant Response for No Control
    Detail your observations of the primary instability, the shape of the sinusoid, frequency etc.
2. Stabilization with Proportional Feedback Control
    Describe the set up and the behavior of the system and signals for various values of the feedback gains.
3. Closed Loop Identification
    Describe the random signal input schemes used. Include your identified closed loop models data.
5. Analysis
    Find a pole/zero transfer function fit for the closed loop data. Determine the open loop plant model. Verify that the open loop plant model explains the various observed phenomena, i.e. (a) open loop instability at the observed frequency, (b) the fact that proportional feedback control stabilizes this instability, and that (c) at higher gains, a secondary instability is activated (make sure frequency of the secondary instability observed matches that predicted by your model).