EEE342 Prelab Report #3

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1. Introduction

The purpose of this preliminary lab is to encourage the students to think about, as well as to improve their ability in identifying and formulating, real life engineering problems and to propose possible solutions for them considering various issues (e.g. economic, political, social, environmental, etc.). In the first question, a gas storage location is proposed in Türkiye, based on economic, political, social and environmental issues. Then, the possible problems that may be encountered during gas storage/distribution process is discussed. In the final part, a stable system is designed regarding the design specifications given. At the end, the system's stability is examined by plotting its Bode plot.

2. Laboratory Content

2.1 Proposing a Possible Geographical Location of the Gas Storage Tank

"Nabucco Gas Pipeline" project is put into practice to supply natural gas from Middle East and Caspian countries to Austria via Turkey, Bulgaria, Romania, and Hungary respectively [1].

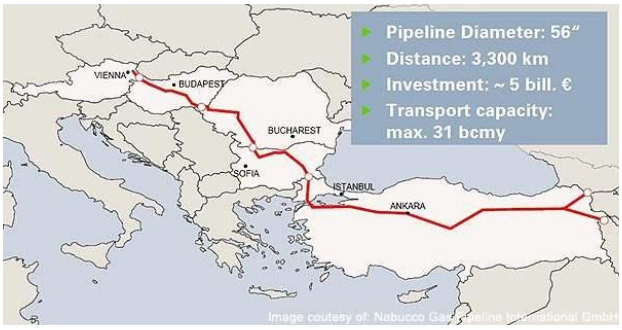

Fig. 2: *Nabucco Gas Pipeline route [2].*

The pipeline, which was to begin construction in 2012, will run for 3,300km (2,050 miles) across the European continent and provide a new competitive gas supply for Western Europe when it is completed in 2015.

The project is expected to cost about €7.9bn ($10.9bn) to construct and will be designed for a gas transport capacity of 31 billion cubic metres (bcm) a year, although initial supplies are likely to be between 4.5 billion and 13 billion cubic metres a year.

The project will transport 1,550bcm of natural gas to Europe for over 50 years, when operational at full capacity. It is expected that the project will generate about 7,000 direct jobs and boost the European economy [2].

Based on the analysis of the Nabucco pipeline route, the Tuz Gölü (Salt Lake) Basin (specifically the Sultanhanı area south of Ankara) is the optimal location for the gas storage facility [3].

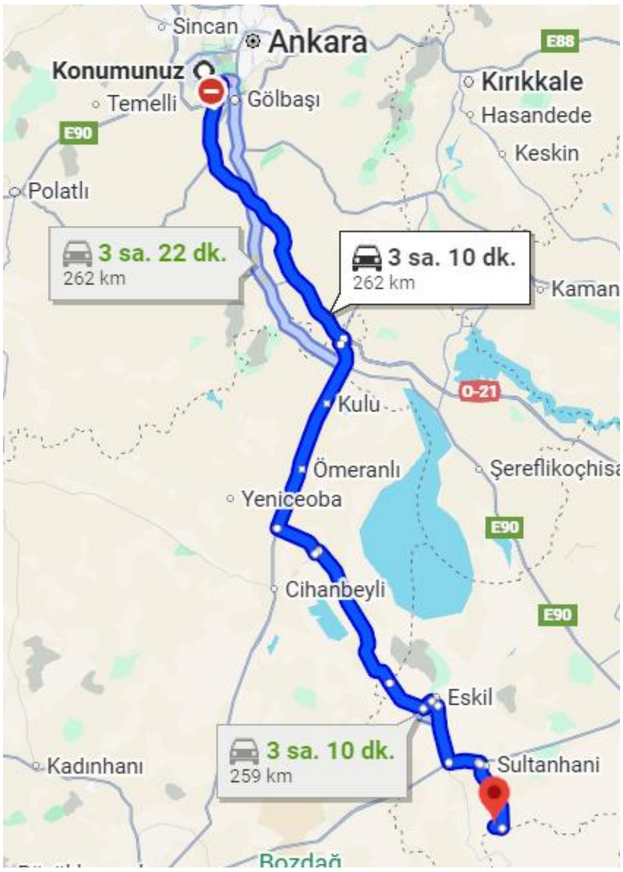

Fig. 1: Distance between Tuz gölü and Bilkent University Campus.

Economic Factors: The geological formations in this region allow for underground salt cavern storage. This method involves leaching salt to create large caverns, which is significantly more cost-effective for high-volume storage compared to constructing above-ground steel tanks. Additionally, its proximity to the Ankara node minimizes distribution costs to Turkey's primary consumption hub while serving the transit line to Europe efficiently.

Political Factors: Locating the strategic reserve in Central Anatolia, near the capital city of Ankara, offers high security. The region is politically stable and distant from volatile border conflicts (unlike Eastern Anatolia). This central location allows the government to secure the energy supply quickly during international crises.

Social Factors: The construction and operation of a high-tech storage facility in Central Anatolia will create skilled engineering jobs and improve infrastructure in a developing region. This supports decentralized industrialization, reducing the economic migration pressure on western metropolitan cities like Istanbul.

Environmental Factors: Underground storage has a minimal surface footprint compared to tank farms, preserving the visual landscape. Modern engineering allows surface facilities to be situated kilometers away from the shoreline, ensuring that the sensitive breeding grounds of the flamingos in the Specially Protected Area are not disturbed.

2.2 Possible Problems

Seismic Activity and Fault Crossings: The Nabucco pipeline route traverses the North Anatolian Fault Zone, one of the most seismically active regions in the world. A major earthquake could cause significant ground displacement, potentially shearing the pipe and causing catastrophic explosions [4]. To solve this, engineers must employ "strain-based design" rather than traditional stress-based design. This involves using high-grade steel capable of plastic deformation and installing flexible joints or "sliding" supports at fault crossings to absorb ground movement without rupturing [5].

Corrosion and Material Degradation: Buried steel pipelines are constantly exposed to soil moisture and electrochemical reactions, which is the leading cause of long-term leaks and structural failure [6]. The standard engineering solution is a dual-protection system. First, a 3-Layer Polyethylene (3LPE) coating is applied to physically isolate the steel from the environment. Second, an Impressed Current Cathodic Protection (ICCP) system is installed to apply a continuous electrical current that prevents oxidation at any point where the coating might be damaged [6].

Geopolitical Supply Instability: The Nabucco project relies on gas suppliers in politically volatile regions (e.g., the Caspian Basin and Middle East). Political disputes or conflicts—such as those seen between Russia and transit nations—can lead to sudden supply cuts that engineering cannot fix [7]. The solution lies in supply diversification. Instead of relying on a single country, the project must secure binding "Take-or-Pay" contracts with a portfolio of different nations (e.g., Azerbaijan, Turkmenistan, Iraq) to ensure that if one source fails, others can compensate [8].

Security and Sabotage: A pipeline stretching over 3,000 km through remote territories is a soft target for theft, vandalism, or terrorist attacks, which are impossible to prevent with physical guards alone [9]. A non-engineering (strategic) solution supported by technology is the implementation of Distributed Acoustic Sensing (DAS). By burying a fiber-optic cable alongside the pipeline, security centers can detect the specific vibration signatures of unauthorized digging or vehicles in real-time, allowing for rapid intervention before the pipe is breached [9].

2.3 Bode plot of the system

The system depicted in below figure is going to be designed to store the incoming natural gas. *A* denotes the base area and *a* is the pipe area. By assuming $h(t) > h_0$ all the time, namely, the amount of gas in the tank Is enough so that both pipe function without stoppage, the mathematical model of the system is going to be deduced. Also, an additional controller need to be designed in order to assure stability. The controller function is given below:

$$G_c(s) = \frac{K(s+a)}{s(s+b)}$$

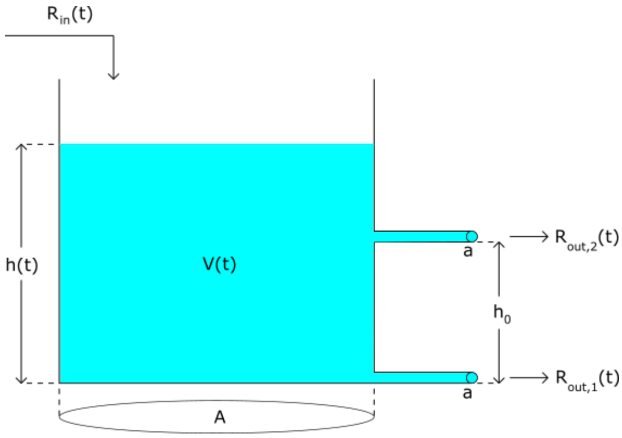

Fig. 3: Gas storage system that is to be designed.

The objective of this section is to design a control system that regulates the gas level $h(t)$ in the storage tank. We first derive the mathematical model of the plant, calculate the specific parameters based on the student ID, and then design a controller to ensure stability.

To start, we will begin with the conservation of mass. The rate of change of the volume inside the gas tank will be the difference between gas going in and gas going out of the tank.

$$\frac{dV(t)}{dt} = R_{in}(t) - R_{out}(t)$$

The expression $R_{out}(t)$ can be rewritten using the given flow equations.

$$R_{out,1}(t) = a\sqrt{2gh(t)}$$
$$R_{out,3}(t) = a\sqrt{2g(h(t) - h_0)}$$

We can rewrite the rate of change in the volume as follows:

$$A\frac{dh(t)}{dt} = R_{in}(t) - \left(a\sqrt{2gh(t)} - a\sqrt{2g(h(t) - h_0)}\right)$$

Next step is to linearize this equation around $h_{nominal}$. To do that, we define a nonlinear flow function f(h).

$$f(h)a\sqrt{2gh} - a\sqrt{2g(h - h_0)}$$

The linearized coefficient K_{linear} is the rate of change of f(h) evaluated at $h_{nominal}$. The equation for K_{linear} is given below:

$$K_{linear} = \frac{\partial f}{\partial h_{nominal}}$$
$$= a\sqrt{\frac{g}{2}}\left(\frac{1}{\sqrt{h_{nominal}}} + \frac{1}{\sqrt{h_{nominal} - h_0}}\right)$$

Thus, the linearized differential equation becomes like this:

$$A\frac{dh(t)}{dt} + K_{linear}h(t) = R_{in}(t)$$

By taking the Laplace transform of the above equation, we get the $G_p(s)$ transfer function.

$$G_p(s) = \frac{1}{As + K_{linear}}$$

My student ID is “22003656”. The necessary values are given below.

- ID: 22003656
- Sum of digits: 2+2+0+0+3+6+5+6 = 24
- Base area (A): $24^2 = 576$ m^2
- Pipe area (a): $\frac{24}{8} = 3$ m^2
- h_0: 5 m
- V_0: $A \times 9m^3 = 216m^3$
- $h_{nominal}$: 9 m
- g: 9.81 m/s^2

Using these values, K_{linear} value is calculated.

$$K_{lineaer}: 3\sqrt{\frac{9.81}{2}}\left(\frac{1}{\sqrt{9}} + \frac{1}{\sqrt{9-5}}\right) = 5.537$$

Therefore, plugging in the calculated values in $G_p(s)$ transfer function will give the following:

$$G_p(s) = \frac{1}{576s + 5.537}$$

It is known that $G(s) = G_p(s) \times G_c(s)$. The transfer function of $G_c(s)$ is given below again:

$$G_c(s) = \frac{K(s+a)}{s(s+b)}$$

I will use the following values for K, a, and b:

$$G_c(s) = \frac{1000(s+1)}{s(s+4)}$$

The bode plot of the system is extracted using MATLAB. Fig. 4 depicts the magnitude and phase Bode plot.

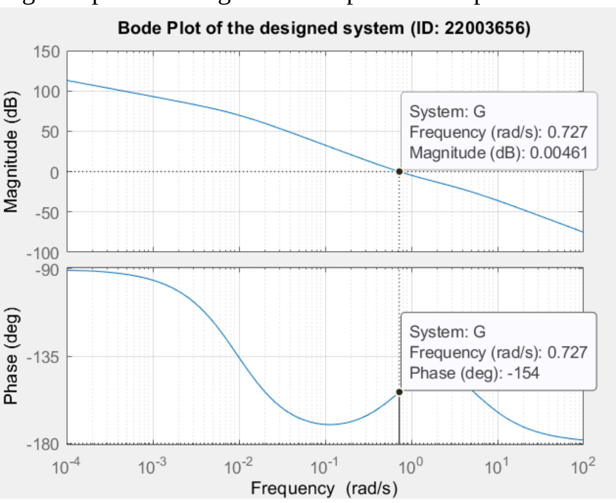

Fig. 4: Bode plot of the designed system.

```
--- Stability Margins ---
Gain Margin: Infinite dB
Phase Margin: 26.46 deg at 0.73 rad/s
Delay Margin: 0.6357 sec
```

Fig. 5: Stability margin values of the designed system.

The stability margins of the system are given above. The results show that the designed system is stable.

3. Conclusion

In this preliminary work, a stable system is designed. The transfer function of the system is deduced considering the design specifications. The Bode plot of the system is plotted in MATLAB and gain, phase, and delay margins of the system was found, and stability of the system is discussed.

4. MATLAB CODE

```
% Student ID: 22003656
digits = [2 2 0 0 3 6 5 6];

% A (Base Area)
A = sum(digits)^2; % Sum=24, A=576

% a (Pipe Area)
a_pipe = mean(digits); % Mean=3.0

% System Constants
h_nom = 9;    % Nominal height (m)
h0 = 5;       % Height of second pipe (m)
g = 9.81;     % Gravitational acceleration
(m/s^2)

term1 = 1 / sqrt(h_nom);
term2 = 1 / sqrt(h_nom - h0);
K_lin = a_pipe * sqrt(g/2) * (term1 +
term2);

fprintf('Calculated A: %.2f m^2\n', A);
fprintf('Calculated a: %.2f m^2\n',
a_pipe);
fprintf('Calculated K_linear: %.4f\n',
K_lin);

num_p = 1;
den_p = [A K_lin];
Gp = tf(num_p, den_p);

K_gain = 1000;
a_c = 1;
b_c = 4;

num_c = K_gain * [1 a_c];
den_c = [1 b_c 0];
Gc = tf(num_c, den_c);
G = Gp * Gc;

figure;
margin(G);
grid on;
title('Bode Plot of the designed system
(ID: 22003656)');

% Extract and Display Margins
[Gm, Pm, Wcg, Wcp] = margin(G);
fprintf('\n--- Stability Margins ---\n');
if isinf(Gm)
    fprintf('Gain Margin: Infinite dB\n');
else
    fprintf('Gain Margin: %.2f dB at %.2f
rad/s\n', 20*log10(Gm), Wcg);
end
fprintf('Phase Margin: %.2f deg at %.2f
rad/s\n', Pm, Wcp);

% Check Stability
if Pm > 0
    disp('Result: The closed-loop system
is STABLE.');
else
    disp('Result: The closed-loop system
is UNSTABLE.');
end
```

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