Meca 482

California State University Chico

Final Project Report:

Rotary Flexible Link

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Introduction

The objective of this project is to control the position of the servo motor while minimizing the oscillations of the flexible link. The Rotary Flexible Link consists of a strain gage which is held at the clamped end of a thin stainless steel flexible link. The motor on the rotary servo base unit is used to rotate the flexible link from one end in the horizontal plane. The motor end of the link is instrumented with a strain gage that can detect the deflection of the tip. The strain gage then outputs an analog signal proportional to the deflection of the link.

Research on flexible robotic manipulators has gained new potential with the recent interest in assistive robotics and cooperative human-robot interaction. The low inertia and natural compliance of the links represent additional safety features that can be explored in robot design. The biggest challenge posed by this type of devices is the control of vibrations that arise from motion and the mechanical flexibility of the links.

Modeling

The Rotary Flexible Link model is shown in Figure 1. The base of the flexible link is mounted on the load gear of the servo. The servo angle, θ, increases positively when it rotates counter-clockwise (CCW). This enables the servo and the link to turn in the CCW direction, shown in figure 2, when the control voltage is positive. The flexible link has a total length of 0.419 m, a mass of 0.065 kg, and its moment of inertia about the center of mass is 0.0038 kg- m^2 . The deflection angle of the link is denoted as α and increases positively when rotated CCW

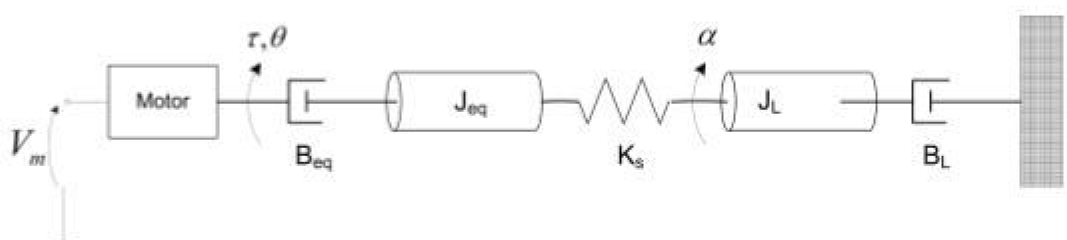

Figure 1: Model of link and Motor

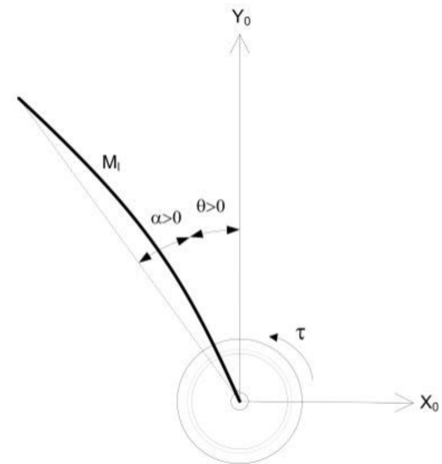

Figure 2.1: Rotary Flexible Link Angles

Figure 2: Rotation of the link CCW

The equations of motion involving a rotary flexible link, involves modeling the rotational base and the flexible link as rigid bodies.

Transfer Function of Mechanical Model-

$$G(s) = \frac{\theta_2(s)}{T(s)} = \frac{K}{\Delta}$$

$$\text{Where } \Delta = \begin{bmatrix} J_{eq}s^2 + D_1 s + k & -k \\ -k & J_L s^2 + D_2 s + k \end{bmatrix}$$

$J_{eq} = 0.00208\ kg - m^2$
$J_L = \ 0.0038\ kg - m^2$
$D_1 = 0.015\ N/m$
$D_2 = 0.01\ N/m$
$k = \frac{3\,EI}{l^3}$ = 2.5399 N/m (stiffness of link)

<u>Sensor Calibration</u>

For this project, the sensor feedback that we will be using is a strain gage and the servo as a stepper with encoder for a precise rotation with a small angle of rotation. Since we know that the servo can work with small angles and we know it is the heart of the machine, making for a smooth translation. Knowing a servo works with electrical frequencies, we know that it can be controlled directly from the microcontroller which would carry the code. Since we can control the speed and angles to obtain a strain/(angle velocity) slope which would help us for a smooth translation. With this we know we can get a smooth translation, using the known distance we would want to use and the speed it would need to accelerate or decelerate to obtain the distance. To get a correct feedback a calibration of the sensor has to be done, where a known weight or a known movement will be implemented to see the reaction of the sensor, with this we could create an equation from plotting known values. With this equation a very rough "speed vs placement", yet since it is too rough it would have some oscillation. By applying a PID "guessing" until obtaining the desired smoothness, regardless of position and the speed, it needs to get there with the PID it would overshoot and undershoot until a more reasonable answer would appear.

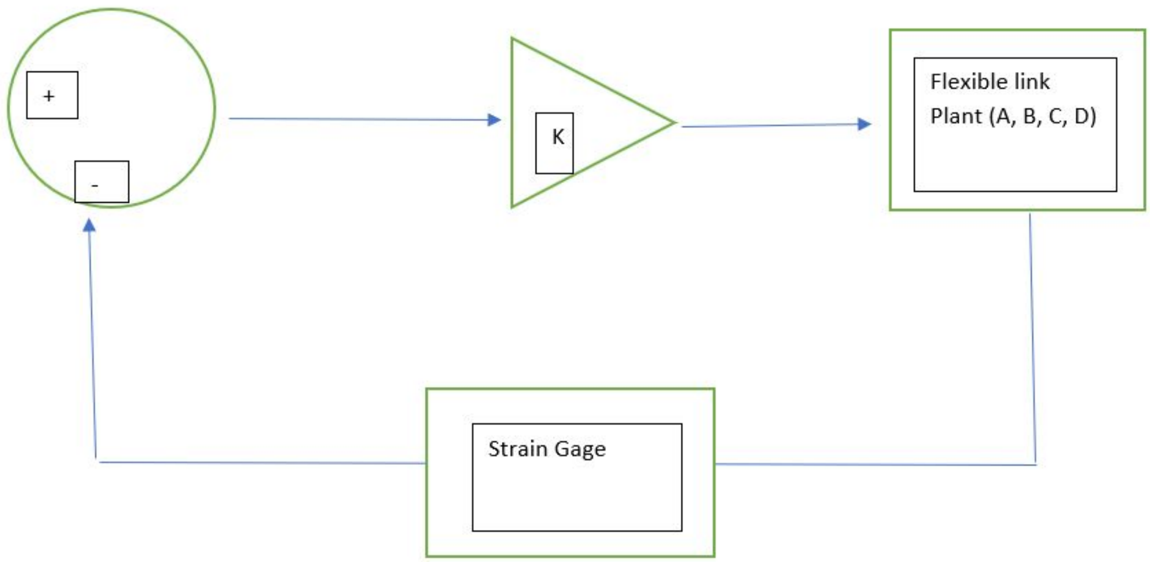

Figure 3: Simplified Feedback Control

As mentioned the project has a Feedback control, where the strain gage works as any sensor, where it gets a reading and depending on what the sensor "feels" it will give a signal to the microprocessor.

<u>Controller Design and Simulation-</u>

For the controller we will be using a simple microcontroller, the team chose the Arduino uno, since it is very economical, simple to use, and the team members had previous experience with such a device. Since this project is just controlling a Servo motor, and it only has one input signal from the strain gage. The output of the sensor is a very weak signal, an amplifier opamp of single input 5V to assure that the microcontroller will be able to read the signal yet not burn the device. For this system control we will need only 2 pins of the microcontroller, one for the input signal coming from the sensor/amplifier and the other one for the output of the servo motor.

The objective of the controller is to stabilize the system “asymptotically”. This means the system will stabilize itself with detection of the error everytime the angle of the link tip is in motion and decrease it everytime. Using our transfer function a root locus plot was found in matlab to find the location of the closed-loop poles of the systems.

Appendix A: Matlab Code

```
clear; clc;

numg= 2.5399;
deng=[7.904^-6 7.78^-5 0.01508 0.06349 6.4510];
sys=tf(numg,deng);
step(sys)
impulse(sys)
t=0:0.01:5;
[y,t]=step(sys,t);
plot(t,y) % natural frequency of link
%%
[A,B,C,D]=tf2ss(numg,deng)% Convert tf into a ss equation for modeling
rlocus(sys)
p=pole(sys)
zeta = 0.07998;
wn = 6.25;
sgrid(zeta,wn)

k=1.1107 % determined from poles of rlocus plot
[k,poles] = rlocfind(sys)
sys_cl = feedback(k*sys,1)
step(sys_cl)
```

References

Nise, N. S. (2015). Step by step instructions for constructing transfer function, state space, root locus, etc. Control systems engineering (7th ed.). New York, NY: John Wiley & Sons. (157-447)

Rotary Flexible Link. General information about rotary flexible link, with additional lab information (Simulink/Labview) https://www.quanser.com/products/rotary-flexible-link/. Accessed 20 Dec. 2019.