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ME3003

Introduction to Flow Sensors and Datasheet Reading

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Abstract

Data acquisition is one of the crucial steps of designing a mechatronic system. Changes in the environment must be observed for decision making purposes.

Sensors can be seen anywhere such as natural or man-made objects. The natural sensors, like those found in living organisms, usually respond with signals having electrochemical character. In man-made devices, information is also transmitted and process in electrical form. Application for sensors is almost limitless, from simple system such as car door monitoring arrangement to extremely complex one like Mars Exploration Rover – B.

Since the topic about sensors is so vast and technical, designing a complex sensor is beyond the scope of this report. Therefore, in our project, we only focus on flow sensor, and specifically how to make the best of the sensor catalog. This goal includes what parameters are important in choosing the right flow sensor for one's project, expected failure modes during operation and maintenance of the sensor, which makes the report somewhat practical in designing the system as a whole.

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Chapter 1

Modeling the motor

1.1 Electrical modeling

In this modeling project, the motor is DC brushed type. The type of control is field control, which means the armature supply voltage is fixed.

The magnetic torque of the motor is generated by the interaction of the stator field and the rotor field and is given by

$$T_m(t) = k i_g i_f(t) \tag{1.1}$$

where

- $T_m(t)$ is the motor torque.
- i_g is the rotor current (i.e. armature current).
- $i_f(t)$ is the stator current (i.e. field current).
- k is a constant. The value depends on the motor's characteristics.

Since the supply voltage for the armature is constant, the product $k i_g$ is replaced with k_g to simplify the equation. Thus, equation 1.1 becomes $T_m(t) = k_g i_f(t)$.

The field circuit equation is

$$v_f(t) = R_f i_f(t) + L_f \frac{d i_f(t)}{dt} \tag{1.2}$$

where $v_f(t)$ is the supply voltage to the stator; R_f is the resistance of the field windings; L_f is the inductance of the field windings.

Substituting $i_f(t)$ in equation 1.2 with $T_m(t)$ in equation 1.1 yields

$$v_f(t) = R_f \frac{T_m(t)}{k_g} + \frac{L_f}{k_g} \frac{dT_m(t)}{dt} \tag{1.3}$$

Using Laplace transform, equation 1.3 becomes

$$V_f(s) = T_m(s) \left(\frac{L_f}{k_g} s + \frac{R_f}{k_g} \right) \tag{1.4}$$

1.2 Mechanical modeling

The motor has its own inertia J_m and viscous damping coefficient b_m. Therefore, equivalent parameters are necessary to form relations between the rotational output load $\theta_L(t)$ and motor torque $T_m(t)$.

From machine element course, it is known that the relation between torque, rotational displacement and number of teeth follows the formula (assuming negligible backlash):

$$\frac{T_1}{T_2} = \frac{\theta_2}{\theta_1} = \frac{N_1}{N_2} \tag{1.5}$$

where

- T_1 is the torque generated by gear 1.
- T_2 is the torque generated by gear 2.
- θ_2 is the rotational displacement of gear 2.
- θ_1 is the rotational displacement of gear 1.
- N_1 is the number of teeth of gear 1.
- N_2 is the number of teeth of gear 2.

Using equation 1.5, the motor and load is related by

$$\frac{T_m(t)}{T_L(t)} = \frac{\theta_L(t)}{\theta_m(t)} = \frac{N_1}{N_2} = \frac{T_m(t)}{\left(J_e \frac{d^2\theta_L(t)}{dt^2} + b_e \frac{d\theta_L(t)}{dt}\right)} = n \tag{1.6}$$

where

- $T_L(t)$ is the torque of the load.
- $\theta_L(t)$ is the rotational displacement of the load.
- $\theta_m(t)$ is the rotational displacement of the motor.
- $J_e = J_m\left(N_2/N_1\right)^2 + J_L$ is the equivalent inertia of the motor and load. The inertia is adjusted with gear ratio N_2/N_1.
- $b_e = b_m\left(N_2/N_1\right)^2 + b_L$ is the equivalent viscous damping coefficient of the motor and load. The inertia is adjusted with gear ratio N_2/N_1.
- $n = N_1/N_2$ is the gear ratio.

Using Laplace transform, equation 1.6 becomes

$$T_m(s) = \Theta_L(s)n\left(J_e s^2 + b_e s\right) \tag{1.7}$$

Combining equation 1.4 and 1.7, the required transfer function is

$$V_f(s) = \Theta_L(s)n\left(J_e s^2 + b_e s\right)\left(\frac{L_f}{k_g}s + \frac{R_f}{k_g}\right) \tag{1.8}$$

Rewriting in terms of fraction yields

$$\frac{\Theta_L(s)}{V_f(s)} = \frac{\dfrac{k_g}{L_f n J_e}}{s\left(s + \dfrac{b_e}{J_e}\right)\left(s + \dfrac{R_f}{L_f}\right)} \tag{1.9}$$

References

[1] Jacob Fraden. *Handbook of modern sensors: physics, designs, and applications*. 5th ed. Vol. 1. Springer International Publishing Switzerland, 2016, pp. 453–484.