Attic Hatch Model Implementation Using the Bondgraph

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Abstract

The Bondgraph had been used widely in building and simulating a model. This paper solves a problem in an attic hatch (planar mechanism problem) using Bondgraph approach. *Planar mechanisms* are idealized systems that can translate and rotate in one plane. In the same way as linear translation or uni-axial rotation, planar motions can be considered as a special case of spatial motions of mechanisms. In the attic hatch system, people have to push with lot of power to open it. Then came up an idea to add a mass-pulley mechanism in order to open and close it easily. Before implementing this idea, it needs to simulate it first, because it needs to adjust many parameter combinations. This will also prevent someone to make unnecessary hole while implementing this idea (such as trial and error). This paper only dealt with building and simulating this idea, not going further in the real implementation. The simulation result shows that several parameters should be chosen carefully in order to achieve the final goal, i.e. to open the hatch easily and fast. The 20-Sim simulation package is used to verify the model.

Keywords: Bondgraph, simulation, 20-Sim.

Abstrak

Bondgraph sudah dipergunakan secara luas untuk mensimulasikan sebuah model dari plant. Makalah ini akan membahas permasalahan yang terjadi dalam membuat sebuah attic hatch (pintu ke atap yang biasanya terdapat di rumah-rumah Eropa) dengan menggunakan bondgraph. Attic hatch merupakan suatu permasalahan dalam planar mechanism. Planar mechanism ada system ideal yang dapat bertranslasi dan berotasi dalam satu bidang datar. Seperti pada translasi linier atau rotasi pada satu sumbu, gerakan planar dapat digolongkan sebaagai kasus khusus dalam mekanik. Pada attic hatch,orang harus mendorong pintu untuk membukanya. Sehingga muncul suatu ide untuk menambahkan katrol dan beban untuk memudahkan proses buka dan tutupnya. Untuk menambahkan katrol dan beban ini, perlu dilakukan suatu simulasi untuk menghindari pembuatan lobang yang tidak perlu. Makalah ini hanya membahas simulasi dari sistemnya tanpa memasukkan implementasi secara nyata. Dari hasil simulasi, didapatkan bahwa beberapa parameter harus dipilih secara hati-hati untuk dapat membuka dan menutup pintu dengan mudah. Dalam simulasi ini dipergunakan software 20-Sim.

Kata kunci: bondgraph, simulasi, 20-Sim

1. Introduction

Houses in the Europe usually are equipped with attic room. People can use it as a bedroom or just a place to store something. There is a door called a hatch and people have to push to open it. When the hatch is heavy, it is quite difficult to open it with little energy. Therefore, there is an idea to add a mass-pulley mechanism to make it easy to open. Figure 1 shows this idea.

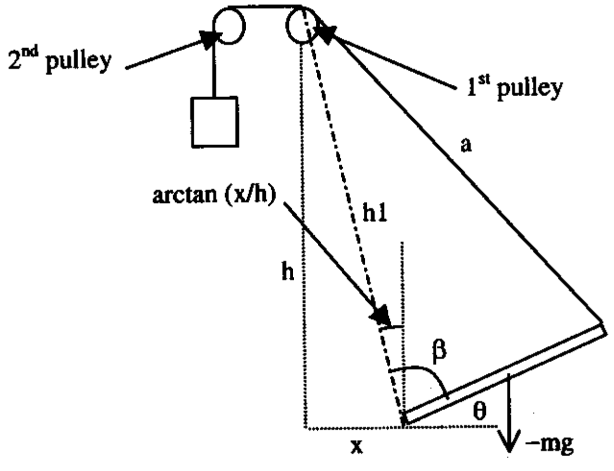


Figure 1. Construction of the idea

Note: Discussion is expected before September, 1st 2004. The proper discussion will be published in "Jurnal Teknik Mesin" volume 6, number 2, Oktober 2004.

There is no specific parameter except h is 1.9–2.2 m. x can be any value. The goal is to open or close the hatch in 3 second with minimum effort. Length of the hatch is 1m with 30 kg weight. Open means hatch has at least 90° with respect to the floor.

This paper only discusses the simulation result. There is no real experiment with the plant. The idea is to show how easy to model planar mechanism in Bondgraph. Model is made from the initial model with coordinate transformation. Later, it is expanded to fulfill the requirements.

2. The Planar Mechanism [1]

The Planar mechanisms are idealized systems that can translate and rotate in one plane. In the same way as a linear translation or a uni-axial rotation, planar motions can be considered as a special case of spatial motions mechanisms. Simple planar mechanism example is pendulum, because it can only move in one plane. More complex example of planar mechanisms is crank-shaft mechanism.

Rigid body has 6-dof (degree of freedom): three for translation (with respect to x, y and z-axes) and three for rotation (around x, y and z-axes). Discussion about planar mechanism can be read in [1].

3. Problem Formulation

First, it needs to identify the problem correctly in order to make a competent model. From planar mechanism point of view, this problem has translation and rotation part. Both are connected each other. The mass will only move in vertical axis (Cartesian coordinate) and the hatch will rotate around certain axis (polar coordinate).

Because this model will use Bondgraph [2] approach, the parameter identification according to this approach is done. Since the two coordinates are related each other, there must be something to connect them. From Bondgraph point of view, the component is TF. For the multiplier factor is not constant, MTF will be used.

In the Cartesian coordinate, I-element will represent the mass. Since the rope is elastic, it can be regarded as a spring. Spring is C-element in Bondgraph. The gravitational force acts on the mass is Se with constant value.

In the polar coordinate, I-element is the hatch. There are two R-elements, one for friction on the hinge and the other for air friction. Between the mass and the hatch, there is a rope. This will enable the hatch to get some torque to open or close it.

Model at Polar Coordinate System

The hatch is connected to the floor via hinges and there is a friction at this point, so we represent this friction as R. The hatch itself is represented as I. For the hatch is moved in the air, there will be an air friction; this will also be represented by R. The gravitational force at the hatch forms a torque that rotates the hatch clock-wise (see figure 1). The magnitude of this torque is the gravitational force multiplied by cosine of • and its distance to the hinge (see figure 1). So we need an MSe to represented this. The MSe needs input and it is supplied by angle. The angle itself is calculated by q-sensor at the polar coordinate system.

Model at Cartesian Coordinate System

At this coordinate system there are two components, i.e. mass (represented by I) and rope (represented by C). The reason for the later is rope has behaviour like a spring and can be modelled by C. If the value of C is large, it means the spring constant is small and vice versa ($k = C^{-1}$). There is a gravitational force at the mass, it is represented by Se with value –mg. The idea of the mass is to use it as a balancing load for the hatch.

4. Initial Model

The initial model can be seen on figure 2. It shows the model of the hatch and the mass related by MTF with certain modulated input. There are two q-sensors. The first is for polar coordinate system (as discussed above) and the other is for Cartesian coordinate system (for 3D simulation).

The following conditions are made for this model:

1. It is assumed that the air friction is squared
2. The hatch can freely hang (so there is a balancing between the hatch and the mass. Beside, there are also hinge and air friction)
3. The rope is not so stiff

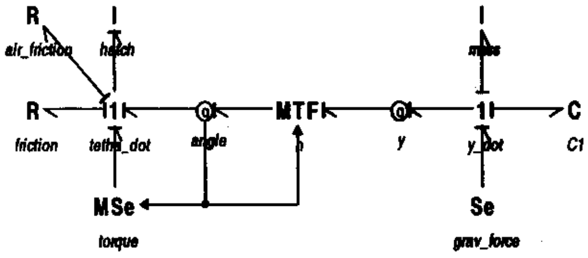


Figure 2. Initial model

To calculate the relation between two coordinate systems, we use the following rules and assumptions:

1. The length of rope (L), see the explanation below.
2. The distance between the first pulley and the tip of the hatch is depend on the angle.
3. The length of the attic is l.
4. y is difference between L and a.

Here, the process of getting the relation between two coordinates is derived. According to cosine rule on the triangle,

$$L = \sqrt{l^2 + h_1^2 - 2lh_1\cos(\pi/2 + \arctan(x/h))} \tag{1}$$

$$h_1 = \sqrt{h^2 + x^2} \tag{2}$$

L is not the real length of the rope, but the distance between tip of the hatch to the 1st pulley while it is closed. From the cosine rule,

$$a = \sqrt{l^2 + h_1^2 - 2lh_1\cos\beta} \tag{3}$$

then β is substitute with $\pi/2 + \arctan(x/h) + \theta$.

$$a = \sqrt{l^2 + h_1^2 - 2lh_1\cos(\pi/2 + \arctan(x/h) - \theta)} \tag{4}$$

For y is difference between L and a, then

$$y = \sqrt{l^2 + h_1^2 - 2lh_1\cos(\pi/2 + \arctan(x/h))} - \sqrt{l^2 + h_1^2 - 2lh_1\cos(\pi/2 + \arctan(x/h) - \theta)} \tag{5}$$

To derive the relation between the two coordinate systems (according to the planar mechanism), we must differentiate both sides of the last equation with respect to t. The result is

$$\dot{y} = -\frac{h_1\sin(\pi/2 + \arctan(x/h) - \theta}{\sqrt{1 + h_1^2 - 2h_1\cos(\pi/2 + \arctan(x/h) - \theta}}\dot{\theta} \tag{6}$$

So we will write this relation in the MTF equation. This relation shows that the MTF needs angle as a modulated input. To get this value, we use the q-sensor at the polar coordinate system.

For simulation purpose, the hinge and air friction are assumed 1 and 20 respectively. Also the spring compliance is 0.015. These parameters are only assumption and it can be different value in different situation. For example, spring compliance depends on the material of the rope. The friction depends on the lubrication for the hinge. For the air friction, the shape of the hatch needs to be considered also.

Simulation with Initial Model

Model will be built and simulated under the 20-Sim [3] simulation package from University of Twente, the Netherlands. The goal of the simulation is to adjust x, h and the mass to meet the 3 s requirement After several simulations (by trial and error) with different combination of parameters, it was found that x is 0.61 m, h is 1.9 m and the mass is 12.2 kg. This combination will make the hatch on the equilibrium state both in open and close condition. To get this combination, the initial condition is used. These parameters should make the hatch close or open according to its initial position. When the initial position is below threshold value the hatch will go to close state, otherwise to the open state. For all response curves, x-axis is time in second and y-axis is angle in radian.

Unfortunately, the close condition is not 0 radian, but 0.05 radian. It's hard to find this combination, since one value influences the other.

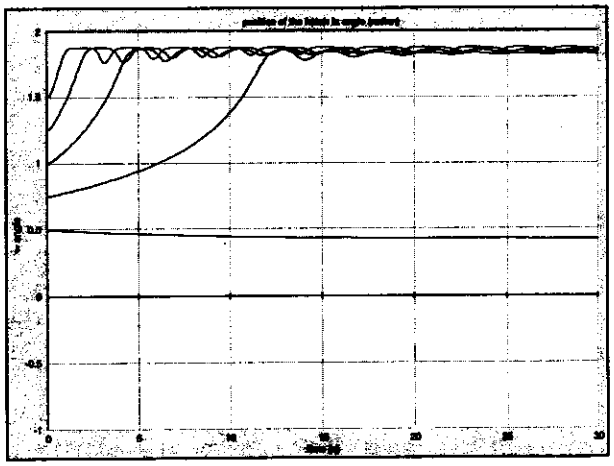


Figure 3. Initial model simulation with several initial condition

Simulation with Final Model

The final model includes the influence of human while opening and closing it. So, MSe is added to the model (see figure 4)

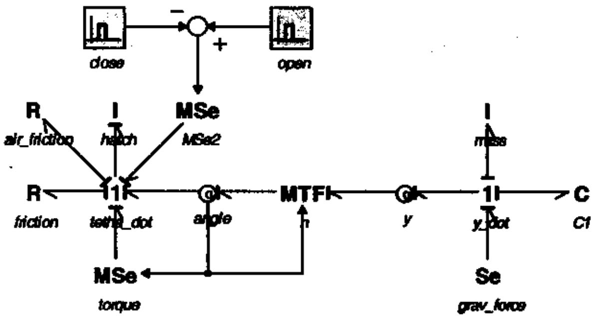


Figure 4. Complete model

From the experiment (trial and error), people only needs 235 N and 200 N to open and close the hatch respectively, instead of 294 N (g = 9.8 m/s). This will full fill the requirement above (to open and close in 3 seconds). All simulation figures show the angle position of the hatch (radian). Figure 5 shows this result.

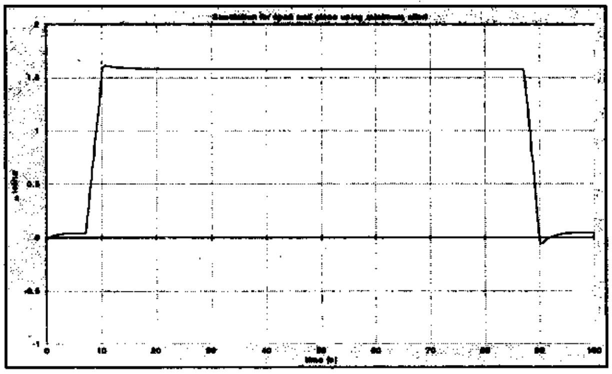
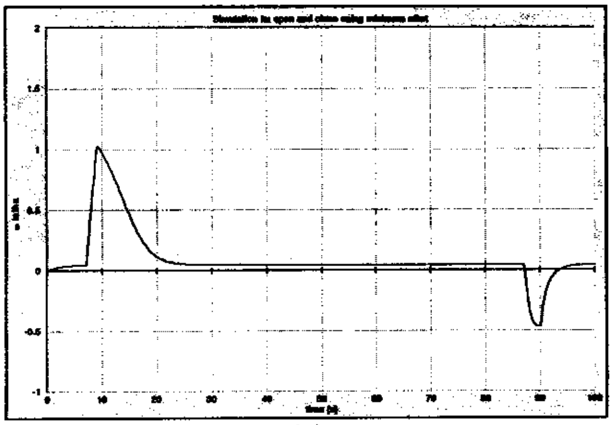
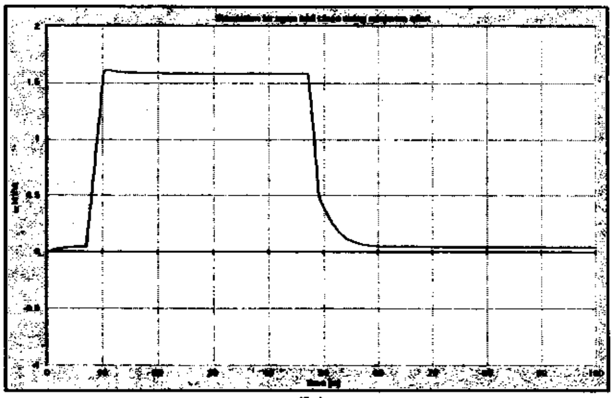


Figure 5. Simulation result with correct parameter

It needs also to simulate this model with different pulse duration to see if this model work or not. Figure 6 will show this.



(a)



(b)

Figure 6. Simulation with different pulse duration:
(a): 2 s and 3 s for open and close respectively,
(b): 3 s and 2 s for open and close respectively

Extension of the Model with Electric Part

To make the hatch open and close with simple electric circuit, we can design a magnetic coil to attract the mass (made of iron) to open and to close the hatch. To attract the mass down means we add virtual mass or gravitational force to this load to open the hatch. If we subtract it with some virtual mass or gravitational force on the load, it means we close the hatch. So we will use a coil to realize this idea. Figure 7 shows the cross sectional of the coil construction.

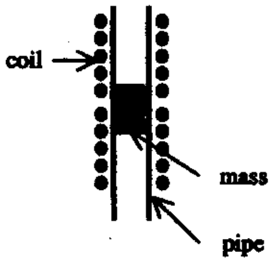


Figure 7. the construction of the open and close coil

The easiest method is to add and to subtract virtual gravitational force on that load instead of to add and to subtract virtual mass. To implement this idea, the simple circuit is designed. It consists of a resistor, coil and source (battery). To add or to subtract virtual gravitational force, we just switch the polarity of the battery. The battery only gives a pulse with certain duration to the circuit to pull down or to push up the mass.

The simple circuit cannot directly be interfaced to the system, because they have a different domain (electrical and mechanical domain). So we use a converter to connect them. We choose gyrator (GY) not TF. The GY will switch effort to flow and vice versa. The 1-junction of the circuit has common flow (current) and this will be converted to magnetic field by the coil, then pull down (open) or pull up (close) the mass like a solenoid. This magnetic field is proportional to the current. So the amount of current flow in the circuit determines how far the solenoid will be pull down or up. In mechanics system, the gravitational force on the mass determines these phenomena. So with the GY, we can convert the current into to the force. That is why we chose using GY instead of TF. Figure 8 shows the modified model by adding electric part to open and close the hatch.

The ratio inside the GY is the number of turn on the coil. The MSe models the battery. It is assumed that there is a circuit to change the polarity of the battery. This circuit is implemented with twos pulse generator. So in the real situation, there will be two buttons, one for opening the hatch and the other for closing it. These buttons are connected to circuit that will change the polarity of the battery.

The battery is 12V 30Ah. So the amplitude of the signal is 12V too. So the other parameter must be set to achieve the goal.

First, the R is chosen to limit the current consumption. The smaller the R, the greater the current consumption of the circuit but the response is good. Unfortunately, the greater the R, the system will not work properly. So the chosen value is 0.005Ω. With the condition that the pulse is only for 3 seconds, we can estimate how long the battery will operate well. For the battery is 12V, the current flow in this circuit is 2.4A. With 30Ah and 3 seconds for every process (open or close only), the power dissipated is $P = i^2 Rt$ and P = 0.0864W. So the battery can be used for 347 processes (theoretically), or 174 times to open and 173 times to close (with initial condition is closed).

The experiment with coil is working; the hatch can be opened by pressing the button but the 3 s requirement cannot be fulfilled. The problem lies on the fact that the battery should be greater than 12 V 30 Ah.

5. Conclusion

It is not so difficult to model planar mechanism problem in Bondgraph, because Bondgraph enable hybrid Bondgraph, where user can add several equation to modulate some element inside the model.

The most difficult problem in modelling planar mechanism in Bondgraph is to get relation between the components inside that model. For this problem is how to derive (6), for this will be the heart of planar mechanism model in the Bondgraph.

The result can be used to realize the system without making unnecessary hole during finding a good position for the pulley. Indeed, we cannot guarantee that we will get the same result due to the unknown parameter such as hinge friction and air friction.

The modified model is working with 12 V 30 Ah batteries but cannot fulfil the 3 s requirement. Using battery with bigger capacity will be helpful.

The 20-Sim as a simulation package is also useful and helpful. Because user can make Bondgraph model and simulate easily. The flexibility of the 20-Sim also enable to model with hybrid Bondgraph.

The model is available as zip file and it can be downloaded from http://faculty.petra.ac.id/hanyf/download/attichatch.zip. This file needs the 20-Sim simulation package. Its viewer version is available on http://www.20sim.com.

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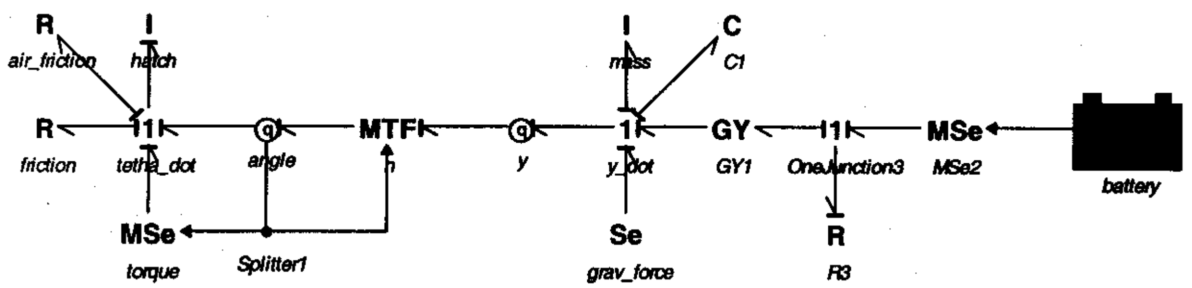

Figure 8. Modified model