Bond Graph Modeling and Simulation of Electromechanical Rescue Hoist System

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Abstract

This study models a helicopter rescue hoist as a bond graph to understand its dynamic behavior. The rescue hoist is a multi-domain system that includes electrical, mechanical-translational and mechanical-rotational domains. The aim of the study is to compare the behavior of the input voltage, current and output transients of a hoist that is loaded as opposed to a hoist that is not loaded. The comparison is done to study the time taken for the system to attain steady state behavior, and to study the size and damping time of transients. The assumption is made of a hovering helicopter that is holding its position constant as long as the study is completed. Also, the effect of the helicopter downwash is neglected in this study.

Keywords: *Rescue hoist, Dynamic Model, Bond graph*

INTRODUCTION

A Rescue Hoist is a device used in Helicopters that is used to pull in (wind up) or let out (wind out) or otherwise adjust the tension of a rope or wire rope (also called "cable" or "wire cable"). In its simplest form, it consists of a spool (or drum) attached to a hand crank or a motor.

Figure 1 Helicopter with rescue hoist [1]

A rescue hoist is used to lower or pull up a load from a hovering helicopter, or transport a hung load from one place to another.
Generally, the motor used is a DC motor or n induction motor. This study considers a 28V DC motor that is generally used in most helicopters. The cable or winch is generally made of braided steel cords but can also be made of other materials like nylon.

Iconic Equivalent of the Rescue Hoist

The first step in analyzing the dynamics of the rescue hoist is to convert the physical system into its iconic equivalent. The iconic diagram is shown below:

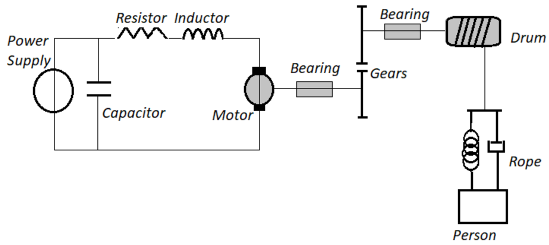

Figure 2 Schematic diagram of Rescue hoist System

The power supply to the system is through the aircraft DC supply. The supply is a constant voltage 28V DC power unit. This source can be through the DC generator, Static inverter or the aircraft battery.
The capacitor shown here is the capacitive equivalent between the power cables. The resistance shown is the combined resistance of the cables as well as the armature resistance of the DC motor. The inductance shown is the armature inductance of the armature winding inside the DC motor.
The output of the DC motor drives the shaft that is connected to the reduction gears by means of bearings. The gears reduce the speed (rpm) of the motor shaft by about 100 times. The second shaft connects the gears to the drum that is used to wind the cable. This connection is also made

via bearings.

The cable itself is made of braided steel. It has some elasticity so that it can flex when carrying load. The elasticity is modeled as a spring and damper as shown in the iconic diagram. The cable is used to carry the overhung load of up to 2000 kg. This weight is modeled as the weight of the person or any other load attached to the cable.

Circuit Diagram with Generalized Variables

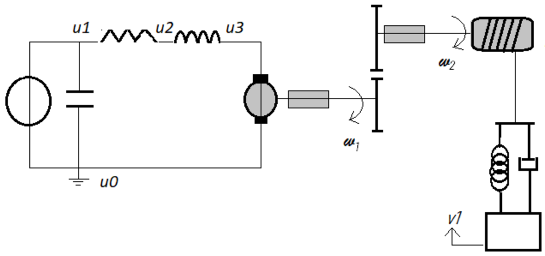

Figure 3 Modeling Frame work with variables

u-voltage; **ω** -angular velocity**; v -** velocity

The iconic diagram is converted to its equivalent circuit diagram.

Voltages are represented by $\mathbf{u_1}$, $\mathbf{u_2}$, $\mathbf{u_3}$.

Angular velocities are represented by ω_1 and ω_2.

The velocity of the load that is pulled up is given by v_1.

BOND GRAPH

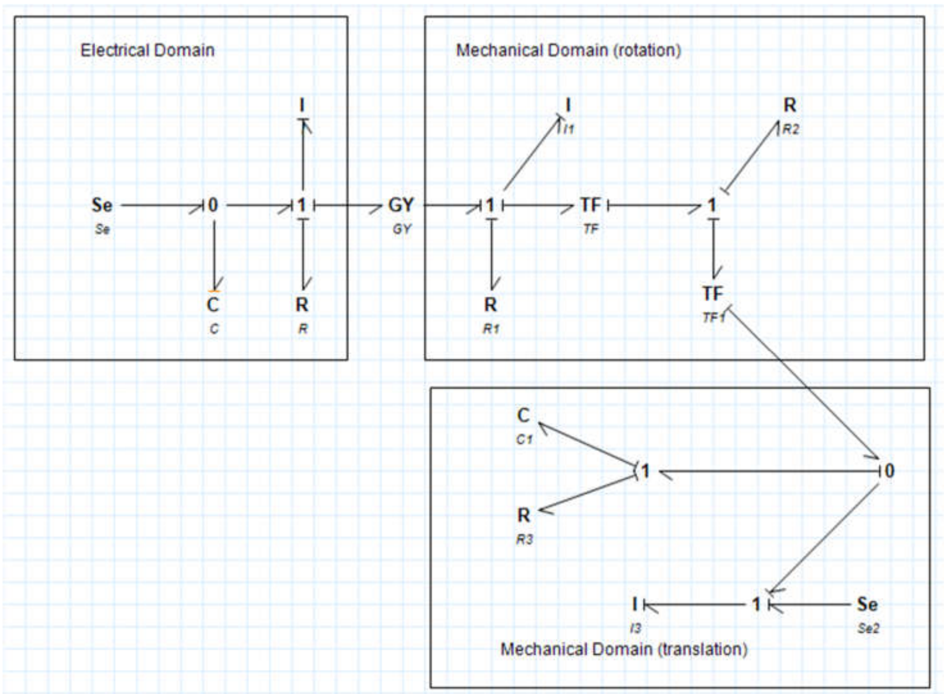

Figure 4 Bond graph for the Rescue Hoist system

- Se – Source Voltage
- C – Electrical Capacitance across the motor terminals
- R – Motor Armature Electrical Resistance
- I – Motor Armature inductance
- GY – Motor modeled as a gyrator (source effort related to response flow)
- R1 – Bearing resistance
- I1 – Motor Inertia component
- TF – Gears modeled as a transformer
- R2 – Bearing resistance
- TF1 – Drum, modeled as a transformer
- C1, R3 – spring and damper model of rope
- I3 – Weight of the person
- Se2 – velocity of the person

Parameters used for bond graph modeling

The physical system is modeled using the following parameters shown in Table 1:

Table 1 System Parameters

Electrical domain
Se – Source Voltage = 28V
C – Electrical Capacitance across the motor terminals = 0.1 micro Farad
R – Motor Armature Electrical Resistance = 2.5 ohms
I – Motor Armature inductance = 1.5 mille Henry
GY – Motor modeled as a gyrator = 0.1
Mechanical Domain (Rotation)
R1 – Bearing resistance = 0.002 N-m-s
I1 – Motor Inertia component = 0.001 N-m-s^2
TF – Gears modeled as a transformer = 0.01 (considering a 100-time reduction gear)
R2 – Bearing resistance = 0.002 N-m-s
TF1 – Drum, modeled as a transformer = 1 (The drum only changes the direction)
Mechanical Domain (Translation)
C1 – spring coefficient = 5 x 10^{-5} (1/k)
R3 – damper coefficient = 50 N-s/m
I3 – Weight of load = 300 kg when loaded and 5 kg on NO LOAD

SIMULATION RESULTS

The simulation is done to compare the behavior of the system with and without load conditions. The loaded condition is considered as a weight of 300 kg (equivalent to three people with luggage slung on the cable). NO LOAD is considered as a 5 kg weight on the cable which is just the weight of the cable itself.

Speed of the winch cable

Figure 5 and Figure 6 shows the speed of winch cable at NO LOAD and loaded conditions respectively. The speed of the winch picks up to about 2 m/s within 2 seconds at NO Load whereas it takes more than 15 seconds to reach 2 m/s under 300 kg load.
This illustrates the inertia (inductor like) behavior of mass. Just like current picks up slowly through an inductor, so does velocity pick up slowly when mass is present.

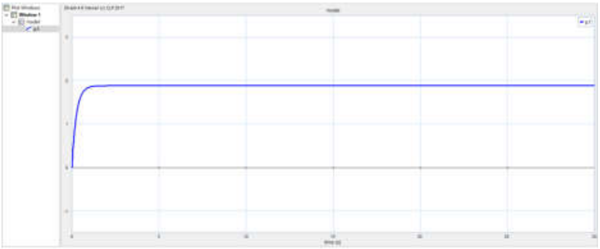

Figure 5 Speed of winch in m/s at NO LOAD

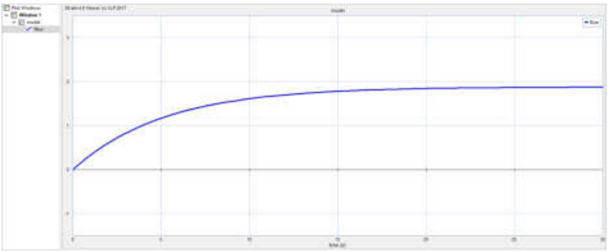

Figure 6 Speed of loaded winch in m/s

Current flow through the motor

Since current is analogous to velocity (both are flow quantities), we see a very similar behavior of current (in Figures 7 and 8) that was seen for speed of the winch.
Under NO LOAD condition (Figure 8), the current subsides and reaches steady state condition within 3 seconds. Whereas, the current takes more than 15 seconds to reach steady state values under load.

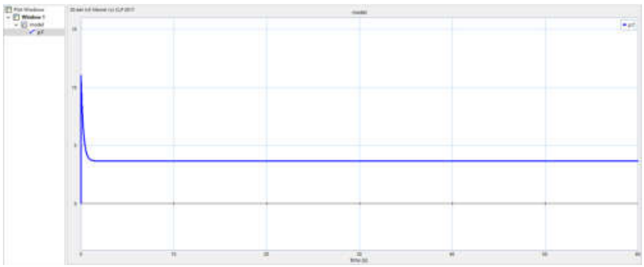

Figure 7 Current flow (A) through motor windings at NO LOAD

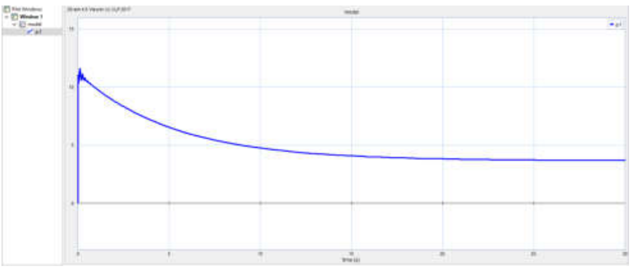

Figure 8 Current flow (A) through motor windings at 300 kg slung load

Peak voltage and transients in the first 2 seconds

Figures 9 and 10 show the voltage transients in the first 2 seconds of starting the motor at NO LOAD and Loaded states respectively.

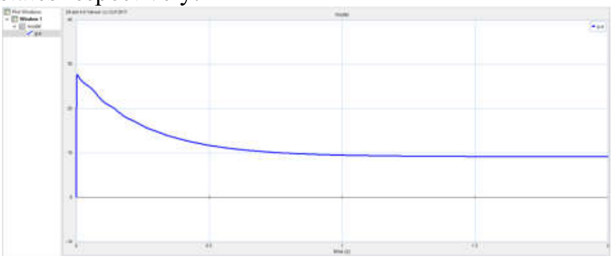

Figure 9 0 s to 2s voltage transients at NO LOAD

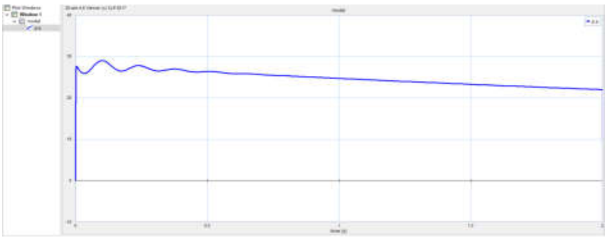

Figure 10 0s to 2s voltage transients at 300 kg slung load

Transient across the cable

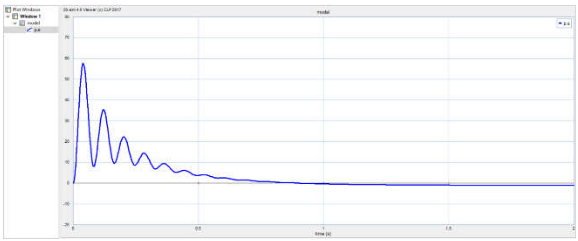

Figure 11 0s to 2s force transients across cable at NO LOAD

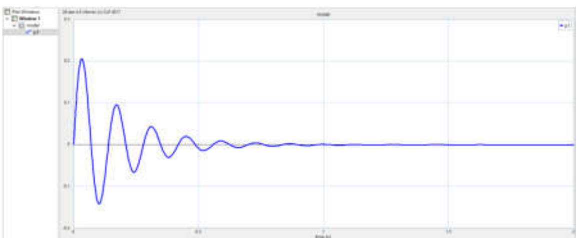

Figure 12 0s to 2s force transients across cable at 300 kg slung load

An interesting phenomenon is evident when the force across the cable is seen for the first two seconds.
Figure 11 shows that when the motor starts pulling up the cable at NO LOAD, the absence of a weight on the cable causes the cable to flail in the air. Since there is no weight pulling it down, the cable experiences only a force in the positive direction. This is analogous to a spring being pulled up with no weight attached to it. There is no balancing force on the other end and hence the force is completely unidirectional.

On the other hand, when a load is present (Figure 12), there is an opposing force that is trying to pull the cable down. This downward force is counteracted by the upward pull of the motor and results in transients both positive and negative.

CONCLUSION

In this study, we have tried to compare the parameters of an electromechanical rescue hoist system under load and no-load conditions. Bond graph modeling is used to bring cross domain physics under a single mathematical domain. 20-sim simulation software has been used for analysis of the model. This study can be utilized to design the physical model since the parameters and their extreme values are perceived in the simulation.
The study ignores the effect of helicopter downwash, ground effect and other physical phenomenon that are invariable present in a real situation. A further improvement in the study can consider these physical effects for a clearer understanding of the system behavior.

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