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# BOND GRAPH ANALYSIS OF THE ENGINEERING SYSTEMS USING 20-SIM SOFTWARE TOOL

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## Abstract

*This paper introduces bond graph analysis of engineering system. Bond graph analysis provides a generalised technique for modelling and analysis of the systems. This is suitable for the analysis of more complex systems. In this paper the fundamental theory of bond graph and its model with simulation using 20-sim software is explored.*

***Index Terms:*** *Bond, Bond graph, Bond graph elements, Iconic representation, 20-sim .*

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## 1. INTRODUCTION

The bond graph modelling has always been a powerful tool for modelling engineering systems. The bond graph philosophy has been emerging since last three decades. The bond graph modelling language represents domain-independent aspect to model a physical system. Bond graph is basically a graphical description of dynamic behaviour of physical system. The description of system from different domain is shown in same format. The most importantly bond graphs are based on energy and energy exchange.

### 1.1Bond Graph Theory

Bond graphs are labelled and directed graphs, in which the vertices represent sub models and the edges represent an ideal energy connection between power ports.The edges are generally referred as bonds. This bonds are used to denote point to point connections between sub model ports.

The form of bond graph is basically a graphical language to describe cross domain physical systems. The bond graph consist of 9 types of atomic elements : energy storage element : the capacitor (C) and inertia (I), a dissipative element, the resistor (R), sources of effort ($S_e$) and flow ($S_f$), the transformer (TF) and gyrator (GY) and two types of junctions (0,1). As bond graph is based on energy exchange the energy is transferred from one element to another by the bond between the elements. Each bond is represented with specific generalised variables the effort (e) and flow (f). They are arranged in such a way that the multiplication of both effort and flow gives the power which is the rate of energy transfer between the connected components. Finally the integral of exchanged power correspond to energy exchange between the components on two sides of the bond. For different domain the effort and flow variables used are different as per the type of domain.

### 1.2 Bond Graph Elements

The bond graph modelling describes atomic interaction of subsystems. The interconnected part is referred as port. The standard form of a bond graph consists of 5 types of one port elements, 2 types of two port elements and 2 types of junctions as multiport elements to define their connections.

One port elements.It includes effort source ($S_e$), flow source ($S_f$), capacitor (C), resistor (R) and inertia (I). One port elements are generalised versions of subsystems in real physical domains. The capacitor and the inertia are called storage elements, their function is to maintain the state of the system by maintaining the energy variables.

Two port elements. It includes transformers (TF) and gyrators (GY) which is used to conserve power. The transformer relates the effort to effort and the flow to flow between its two bonds and the gyrator relates flow to effort and effort to flow between its two bonds.

Multi ports elements. It includes 0-junction and 1-junction. The junctions are use to define the interconnection of the port element. The one port element and two port element can be connected to the junction as well as the junction can be connected to the other junction. The 0-junction is also called common effort junction because it corresponds to a common effort value on each adjacent bond. The 1-junction is also called common flow junction which corresponds to a common flow connection of adjacent bond.

Bonds are represent by half arrow and its direction denotes the positive direction of power exchange between the components. A negative value of power indicate that the direction of power flow is opposite to the direction of the bond.

### 1.3 Use of 20-sim

The 20-sim is a modelling and simulation programme, to simulate the behaviour of dynamic systems such as mechanical, electrical and hydraulic systems or any combination of these is carried out. The 20-sim fully supports graphical modelling, which allows to design and analyse the dynamic system. In this software the model can be enter just like a engineering sketch. The engineering system can be built by choosing components from library and connecting them together.

## 2. OBJECTIVE

The objective is to built a bond graph model of motor with input as a voltage source using 20-sim software by taking reference as an iconic diagram of the system. The block diagram of a system consists of a sub components starting from input to output. According to the each component the connection bond is decided. The complete bond graph is then checked and by using simplification rule the final bond graph is plotted. After this the simulation is carried out and the result in the form of graph is obtained using 20-sim.

## ICONIC DIAGRAM OF SYSTEM

Iconic diagram is the systematic representation of the engineering system. Consider the motor having the input as voltage source. The motor is having the inductance, electric resistance of the coil. Also motor has its own inertia and frictional resistance at the bearing. The iconic diagram of the motor consists of voltage source and the subcomponents of the motor.

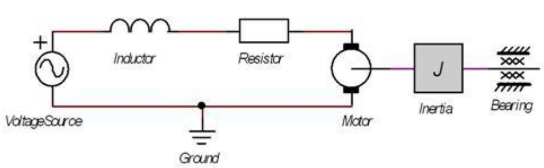


**Fig-1:** Iconic diagram of a motor system

This iconic diagram represents basic elements of the system. The basic element includes voltage source, inductor, motor, motor inertia and resistance at bearing.

Now from this iconic representation the bond graph model of the system is can be modelled using 20-sim software. According to the elements of the system the components are interconnected by a bond.

## 3. BOND GRAPH MODEL

The bond graph model for the motor is divided into two groups

-Input Voltage

-Actual Motor

The input voltage is pass away from inductor and resistor and then to the motor. Therefore the bond graph of an input voltage includes electric potential ($S_e$), inductor (I) and resistor (R). In case of motor the inertia of a motor (I) and the resistance at bearing (R) are taking into consideration.

### 3.1 Bond graph for voltage source

The bond graph of a voltage source consists of effort source, inductance and electrical resistance. The effort source provides input voltage; it is then connected to inductance and electrical resistance as shown.

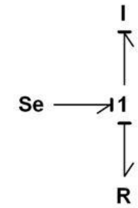


**Fig-2**: Voltage source bond graph

The effort source ($S_e$) is the input voltage source, the storage element (I) is the inductance and another element (R) as a electric resistance combining these elements constitutes a bond graph for the system. The system equations for this system are

static equations:

Se\p.u = Se\effort;

dynamic equations:

I\p.i = I\state / I\i;

R\p.u = R\r * I\p.i;

I\p.u = Se\p.u - R\p.u;

system equations:

I\state = int (I\p.u, I\state_initial);

### 3.2 Bond graph for motor

The bond graph of a motor consists of gyrator, inertia of motor and bearing resistance. The input in the form of voltage as a effort is provided to the gyrator and the output in the form of angular velocity as flow is taken from the gyrator. The figure shows bond graph model for motor.

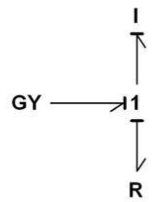


**Fig-3**: Motor bond graph

The gyrator element is the motor, storage element (I) is the motor inertia and another element (R) is bearing resistance are combined to form the bond graph of the system. The system equations are

static equations:
OneJunction1\p1.u = 0;
I\p.T = 0.0;
GY\p2.omega = OneJunction1\p1.u / GY\r;
I\state = GY\p2.omega * I\i;
R\p.T = R\r * GY\p2.omega;
OneJunction\p3.T = I\p.T + R\p.T;
GY\p1.i = OneJunction\p3.T / GY\r;

### 3.3 The complete bond graph

The bond graph for complete system can be developed by connecting the bond graph of two subsystems together. In this development the energy exchange is very important. The energy coming from voltage source is in the form of effort and that is being converted to flow source as angular velocity using gyrator (GY) element. While connecting the element to each other the important parameters are deciding the port and proper interfacing of them according to their causality using interface editor.

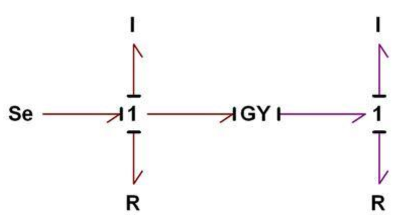


**Fig-4:** Complete Bond graph

The complete bond graph model forms one complete system having specific input as voltage and output as angular velocity of the motor. The revolution per minute of the motor can be calculated from angular velocity. The system equations are
static equations:
Se\p.u = Se\effort;
I1\p.T_out = 0.0;
I\p.u_out = 0.0;

dynamic equations:
OneJunction\p4.u = ((Se\p.u - I\p.u_in) - R\r * (I1\p.T_in / GY\r)) / (1.0 + R\r * ((R1\r / GY\r) / GY\r));
GY\p2.omega = OneJunction\p4.u / GY\r;
I1\state = GY\p2.omega * I1\i;
R1\p.T = R1\r * GY\p2.omega;
OneJunction1\p1.T = R1\p.T + I1\p.T_in;
GY\p1.i = OneJunction1\p1.T / GY\r;
I\state = GY\p1.i * I\i;
R\p.u = R\r * GY\p1.i;

system equations:
I1\p.T_in = algebraic (I1\p.T_out, I1\p.T_in_initial);
I\p.u_in = algebraic (I\p.u_out, I\p.u_in_initial);

### 3.4 Bond graph subcomponents

The complete bond graph model can be represent by separating the bond graph of subcomponents by coloured layer, that facility is available in 20-sim software. The Fig-5 shows the details of the separate portion of bond graph as a subcomponent. The first portion (yellow in colour) shows the bond graph for input voltage source and the second portion (pink in colour) is for motor bond graph.

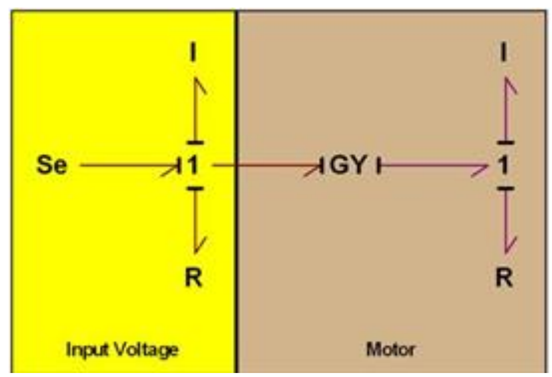


**Fig-5**: Bond graph with subcomponents

## 4. ANALYSIS USING 20-SIM

The analysis of the bond graph is possible with simulator used in 20-sim software. For analysis the system, values of related terms are given in parameters table. After this the x-axis and y-axis are defined. Then by setting time interval on x-axis the simulator is being started. The simulator is run to observe the result of the system. The result is in the form of graph which shows the angular velocity with respect to time. The input voltage supplied is also shown in the form of graph. As the value of voltage is changing the respective value of angular velocity is going to change. The result of analysis is shown in fig-5, in that when the input voltage is 1V the respective angular velocity is 0.5 rad/sec.

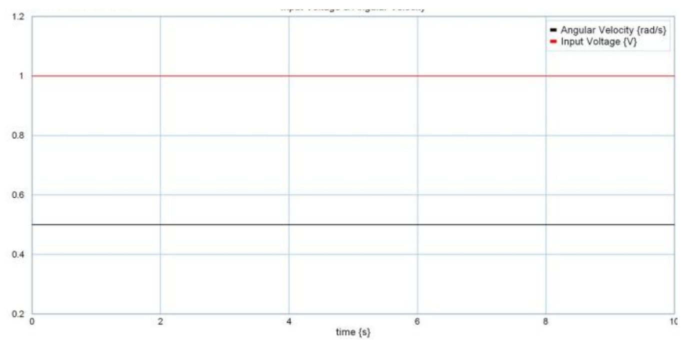


**Fig-6**: Result of analysis

The following table shows the various parameters used in obtaining simulation results

**Table-1: System parameters**

| Parameters | Bond graph element | Value |
|---|---|---|
| Input Voltage | $S_e$ | 1 |
| Inductance | I | 1 |
| Resistance | R | 1 |
| Motor Constant | GY | 1 |
| Motor Inertia | I | 1 |
| Bearing Resistance | R | 1 |
| Angular Velocity | Output Port | 0.5 |

Using the different values of parameters, the analysis of the system can be done. The obtained result is in the form of graph. The above values of system parameters are taken as a standard to understand the simulation.

## 5. CONCLUSION

This paper has presented the study of bond graph analysis with considering the standard example of motor. The aim is to promote the simplified approach for the analysis of engineering systems. Using the bond graph approach the analysis of complex systems is become easy. The port identification and connection provides proper interfacing of various bond graph elements according to the energy exchange. The iconic diagram representation and bond graph approach provides the easy and user friendly facilities to making the models of the various engineering systems. Instead of using other software tools for the making of bond graph, it will better to use 20-sim software, as it has very huge library for the analysis. Using 20-sim software the generation of iconic diagram, block diagram and bond graph model for the various systems is possible. Out of these the proper way to analyse the system is the bond graph method.

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