EVS32 Symposium
Lyon, France, May 19-22, 2019

Automatic Power Flow Generation Algorithm for Automotive Transmission Powertrains

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Executive Summary

In this paper focuses on developing of algorithm for an automatic transmissions of various structures using mathematical method. The analysis was developed using this algorithm.

The angular velocity and torque were consideration and properties such as NVH (Noise, Vibration, Harshness) were not considered. It was defined as a simple planetary gear, double planetary gear, clutch, gear, brake, shaft and inertia in the algorithm.

1 Introduction

The algorithm is expected that it will be used effectively in designing and analyzing transmission of various structures. A automatic transmission composed by the developed algorithm showed the same result as the mathematical analysis of bondgraph method. Therefore, the algorithm verified its validity. The developed algorithm makes it possible to analysis easier.

2 Modelling

The purpose of this research is to automatically generates the power flow of various transmission structures. The algorithm analysing of a combination of several subsystems for defined component of automatic transmission. We implemented an algorithm that automatically generates a power flow by expressing each subsystem as a matrix. The component of automatic transmission was by modelling using the bondgraph method, and the modelling system represented by the bondgraph is expressed and then expressed as a matrix.

2.1 Simple planetary Gear

The planetary gear is the factor that determines the gear ratio in transmission. A planetary gear consisting of sun gear, ring gear and carrier and can be divided into simple planetary gear and double planetary gear. It consists of a sun gear in the middle, a carrier in the form of a pinion gear, and an external ring gear.

The relative angular velocity between each component is given by Equation (1).

$$(\omega_r - \omega_c)N_r = -(\omega_s - \omega_c)N_s \qquad (1)$$

where

ω_c : angular velocity of the carrier

ω_s : angular velocity of the sun gear

ω_r : angular velocity of the ring gear

N_s : number of the sun gear teeth

N_r : number of the ring gear teeth

Figure 1 shows the simple plenatary gear using the bondgraph in terms of angular velocity. In transmission, the three factors of sun gear, ring gear and carrier determine the gear ratio as a combination of fixed, driven and driven.

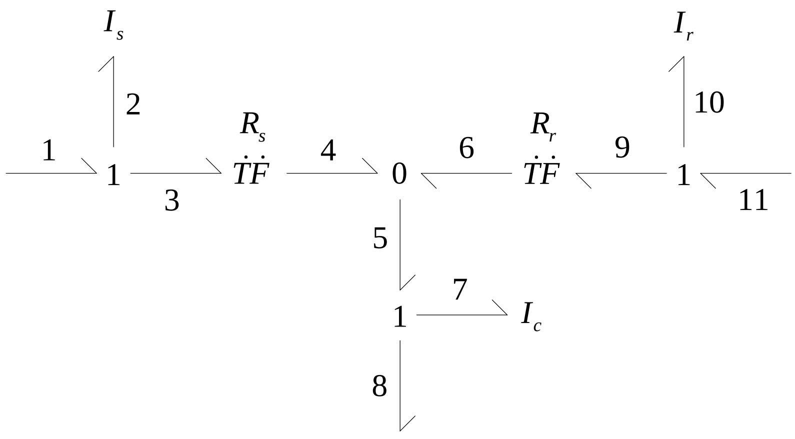

Figure1: Angular velocity bondgraph of the simple planetary gear

where

R_s : gear ratio of the sun gear

R_r : gear ratio of the ring gear

2.2 Double planetary Gear

The double planetary gear has a added pinion set in the simple planetary gear and appears as the difference in the relative speed direction in the carrier. Assuming that the sun gear is driven in the clockwise direction and carrier is fixed and then the ring gear is driven. The pinion adjacent to the sun gear in the carrier will rotate in the counterclockwise direction. The added pinion that constitutes the double planetary gear rotates clockwise and the ring gear rotates counterclockwise.

$$(\omega_r - \omega_c)N_r = (\omega_s - \omega_c)N_s \qquad (2)$$

Compared with eq. (1), which is the relative speed of the simple planetary gear, eq. (2) shows the difference in relative speed direction between the elements. The input and output components of the simple planetary gear and the double planetary gear are the same but are formulated in consideration of the relative speed difference. Figure 2 shows power flow in terms of angular velocity of double planetary gear.

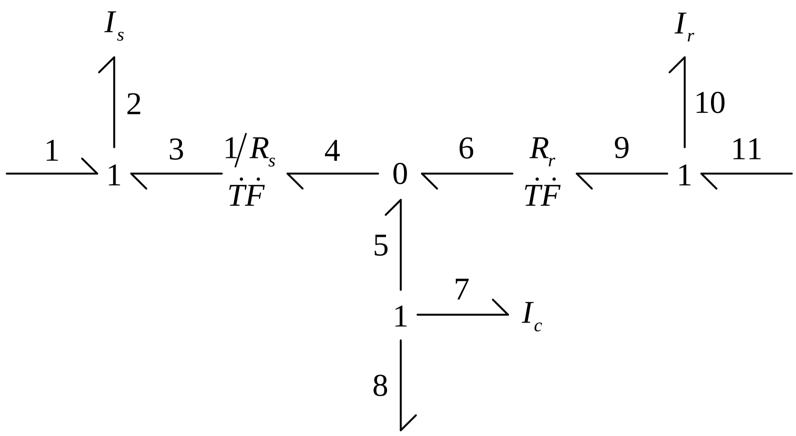

Figure2: Angular velocity bondgraph of the double planetary gear

3 Analysis of Two Simple Planetary Gear Set

Figure 3 shows two simple planetary gear sets with block digaram system. The gear teeth of the two simple planetary gear sets used in the analysis are shown in Table 1.

Table 1: Gear teeth of two simple planetary gear set

	Sun gear teeth	Ring gear teeth
PG1	28	78
PG2	41	86

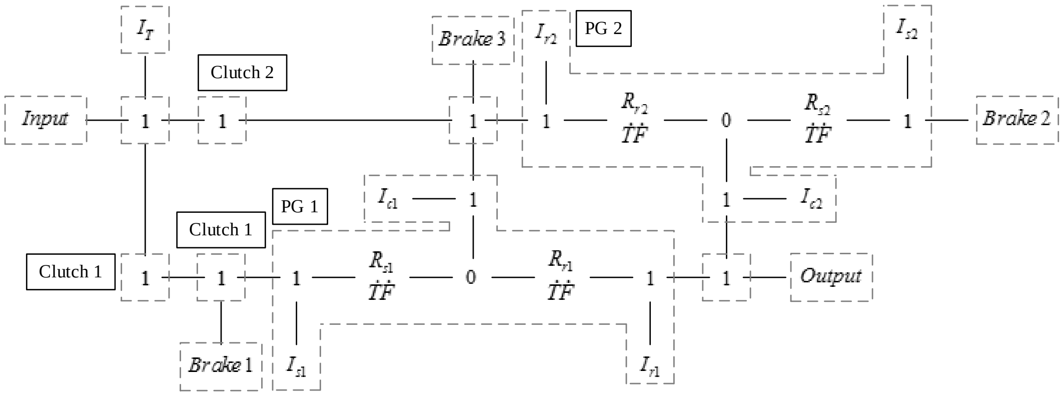

Figure3: Bondgraph of two simple planetary gear set

Figure 4 shows the bondgraph that generated the power flow in the 1st shift of two simple planetary gear sets. The power generated in Brake 2 of Fig. 3 is transferred to the sun gear of PG2 and reflected in the analysis. In terms of angular velocity, the nodes connected to 1-junction receive the same power. Table 2 shows formula of expressed Fig.4.

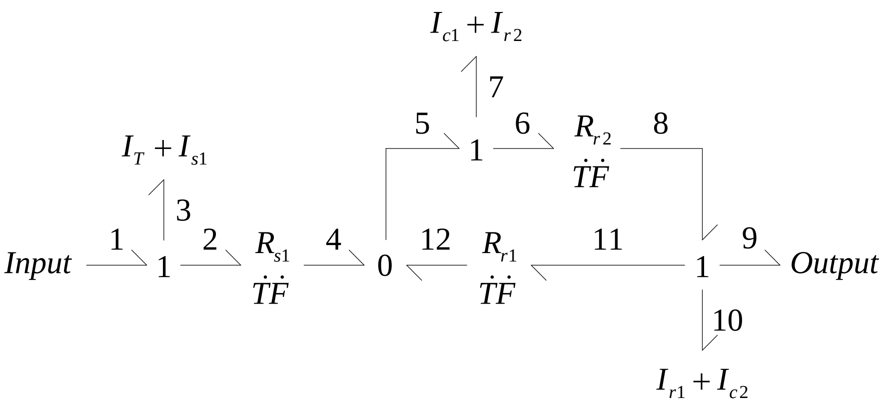

Figure4: Angular velocity power flow on the two simple planetary gear set

Table 2: angular velocity system matrix on two simple planetary gear set

Node	Angular Velocity Relationship	Node	Angular Velocity Relationship
1	$f_1 = \omega_{in}$	7	$f_7 = f_5$
2	$f_2 = f_1$	8	$f_8 = R_{r2} f_6$
3	$f_3 = f_1$	9	$\omega_{out} = f_9 = f_{10} = f_{11} = f_8$
4	$f_4 = R_{S1} f_2$	10	$f_{10} = f_8$
5	$f_5 = f_4 + f_{12}$	11	$f_{11} = f_8$

6	$f_6 = f_5$	12	$f_{12} = R_{r1} f_{11}$

Figure 5 shows the power flow in terms of torque of two simple plenary gear sets using the bondgraph method. The power flow was generated from the inertia torque calculated at the angular velocity and transferred to the system. Table 3 is expressed by formula of Fig.5.

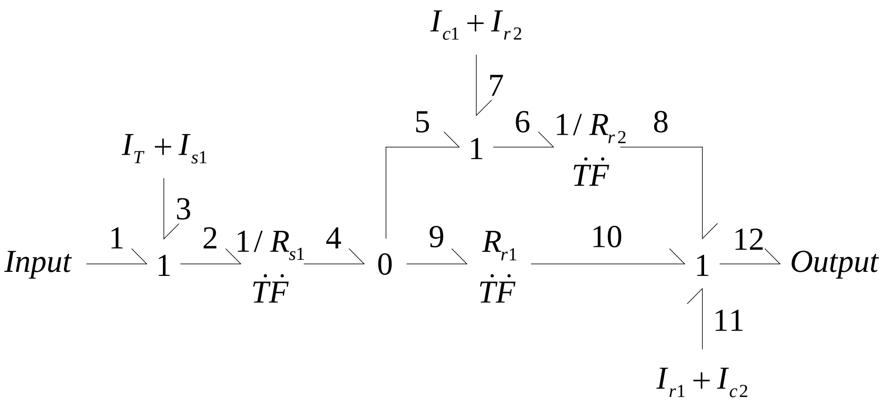

Figure 5: Torque power flow on the two simple planetary gear set

Table 3: Torque system matrix on two simple planetary gear set

Node	Torque Relationship	Node	Torque Relationship
1	$e_1 = e_{in}$	7	$e_7 = (I_{c1} + I_{r2})\dot{\omega}_7$
2	$e_2 = e_1 + e_3$	8	$e_8 = \dfrac{1}{R_{r2}} e_6$
3	$e_3 = (I_T + I_{s1})\dot{\omega}_3$	9	$e_9 = e_4$
4	$e_4 = \dfrac{1}{R_{s1}} e_2$	10	$e_{10} = R_{r1} e_9$
5	$e_5 = e_4$	11	$e_{11} = (I_{r1} + I_{c2})\dot{\omega}_{11}$
6	$e_1 = e_5 + e_7$	12	$e_9 = e_8 - e_{10} + e_{11} = e_{out}$

4 Automatic Power Flow Generation Algorithm

To compare calculation for gear ratio between previous and developed algorithm. To calculate the gear ratio from Table 2. Node 1 to 3 are somed up, it is $f_3 = \omega_{in}$. Another nodes in Table 2 are organized to noed 5, it is eq. (3), so that eq. (4). In the 1st shift of the two simple plenatary gear set, the gear ratio of the anular velocity was calculated to be 0.3565.

$$\frac{1}{R_{r2}}\omega_{out} = R_{s1} + \omega_{in} + R_{r1}\omega_{out} \tag{3}$$

$$\frac{\omega_{out}}{\omega_{in}} = \frac{R_{s1}}{\left(\frac{1}{R_{r2}} - R_{r1}\right)} = 0.3565 \tag{4}$$

In the developed algorithm, the system matrix is consist of submatrix of each components of automotive transmission. The submatrix is compose orthogonality in the matrix and then connecting with some element between each submatrix for power flow. If complete all submatrix is composed and connected, the main matrix is inversed for to know angular velocity and torque at each components.

To calculate using developed algorithm in step 3. First step is compose to submatrix for orthogonality in main matrix. For compose the main matrix need submatrix from modelled components. A eq. (5) is submatrix for modelled simple planetary gear set from Fig.1. A submatrix for modelled the planetary gear set has three matrix because conditions for different input as sun gear, ring gear and carrier. These matrix are modified from eq. (5) using Gauss-Jordan elimination.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -R_s & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -R_r & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Second step is put connect element in main matrix considering power flow. All submatrix are determined column and row for in-out in modelling. The first simple planetary gear set in Fig. 4 is the sun gear and ring gear input, the second simple planetary gear set is the ring gear input, and the sun gear is braked. Considering this power flow, a connect element is constructed in the main matrix.

Third step is to inverse the main matrix. The main matrix modeled the constituent components, the inverse matrix gives the gear ratios of all components.

$$
\begin{bmatrix}
1.0000 & \cdots & 0.0000 \\
1.0000 & & \\
1.0000 & & \\
0.2642 & & \\
0.5265 & & \\
0.2642 & & \\
0.5265 & & \\
0.5265 & & \\
0.3565 & & \\
0.3565 & & \\
0.3565 & \ddots & \vdots \\
0.0000 & & \\
0.0000 & & \\
0.0000 & & \\
0.0000 & & \\
0.3565 & & \\
0.3565 & & \\
0.3565 & & \\
\underline{0.3565} & & \\
0.5265 & & \\
0.5265 & & \\
0.5265 & \cdots & 1.9932
\end{bmatrix}
\tag{6}
$$

The eq. (6) is an inverse matrix consisting of two simple planetary gear sets, and the output element in fig.4 is underlined 19th column in the 1st row. The validity of the developed algorithm is verified with the same results as those calculated by the gear ratio.

5 Conclusion

Equations (4) and (6) show the calculated gear ratio and algorithm results are equal. Automatic transmissions consist of a combination of two or more planetary gear sets and require skill in analysis. The Automatic Power Flow Generation algorithm makes it easier and quicker to analysis.

References

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[2] A. Hedman, 1993,”Transmission Analysis-Automatic Derivation of Relationships”, ASME Vol. 115

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