UNIVERSITY OF PITESTI SCIENTIFIC BULLETIN
FACULTY OF MECHANICS AND TECHNOLOGY AUTOMOTIVE series, year XIX, no.23

DYNAMICS MODELING OF A TORQUE CONVERTER WITH TWO LINKAGE AND INERTIAL MASS

Ion ION-GUTA*
University of Pitesti, Romania

Article history:
Received: 20.7.2013; Accepted: 19.09.2013.

Abstract: *This article describes construction of an model of torque converter with two linkage and two degrees of freedom. This mechanism is a mechanical application of the theory on the transmission of mechanical power by vibrations. The mechanical power is transmitted from engine to the output shaft through a cardanic transmission, two oscillating levers with inertial mass end a unidirectional mechanism. This torque converter is analyzed by AMESim. Dynamics modeling of an automotive application will demonstrate its high performances characteristics. In the modeling of this power transmission system, the stiffness of the shafts and various control logics are included.*

Keywords: torque converter; dynamics modelling; AMESim.

INTRODUCTION

The mechanism proposed to be analyzed in this article is presented in Figure 1. It is composed of a universal joint shaft UJS, an assembly of two bars 1 and 2 connected in coupler point A, an inertial mass m_B mounted at the end of bar 2 and unidirectional mechanism UM.

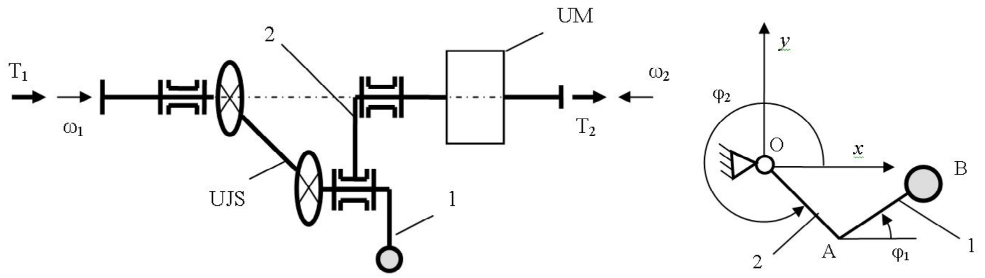

Figure 1. Schematic representation of the torque converter

On the basis of the notations $OA = l_2$; $AB = l_1$, can be writen relations

$$x_A = l_2 \cos\varphi_2 \quad (1)$$

$$y_A = l_2 \sin\varphi_2 \quad (2)$$

$$x_B = x_A + l_1 \cos\varphi_1 = l_2 \cos\varphi_2 + l_1 \cos\varphi_1 \quad (3)$$

$$y_B = y_A + l_1 \sin\varphi_1 = l_2 \sin\varphi_2 + l_1 \sin\varphi_1 \quad (4)$$

where φ_1, φ_2 are the position angles of bars 1 and 2 relative to the axis ox.
Based on the above result

$$\dot{x}_B = -l_2\dot{\varphi}_2 \sin\varphi_2 - l_1\dot{\varphi}_1 \sin\varphi_1 \quad (5)$$

$$\dot{y}_B = l_2\dot{\varphi}_2 \cos\varphi_2 + l_1\dot{\varphi}_1 \cos\varphi_1 \quad (6)$$

The kinetic energy of this mechanical system [1], [2] is

$$E = \frac{J_1\dot{\varphi}_1}{2} + \frac{J_2\dot{\varphi}_2}{2} + \frac{m_B}{2}\left(\dot{x}_B^2 + \dot{y}_B^2\right) \quad (7)$$

* Corresponding author. Email: ion.ion@upit.ro

where J_1, J_2 are moments of inertia of the input and output shaft, and

$$\dot{\varphi}_1 = \frac{d}{dt}\varphi_1 \, ; \; \dot{\varphi}_2 = \frac{d}{dt}\varphi_2 \, ; \; \dot{x}_B = \frac{d}{dt}x_B \, ; \; \dot{y}_B = \frac{d}{dt}y_B \tag{8}$$

Differentiate with respect to time relation (7) is obtained

$$E = \frac{1}{2}\left(J_1^2\dot{\varphi}_1^2 + J_2^2\dot{\varphi}_2^2\right) + \frac{m_B}{2}\left[l_1^2\dot{\varphi}_1^2 + l_2^2\dot{\varphi}_2^2 + 2l_1l_2\dot{\varphi}_1\dot{\varphi}_2\cos(\varphi_1 - \varphi_2)\right] \tag{9}$$

The Lagrange equations [3], [4], [5] for this mechanism can be write as form

$$\begin{cases} \dfrac{d}{dt}\left(\dfrac{\partial E}{\partial \dot{\varphi}_1}\right) - \dfrac{\partial E}{\partial \varphi_1} = T_1 \\ \dfrac{d}{dt}\left(\dfrac{\partial E}{\partial \dot{\varphi}_2}\right) - \dfrac{\partial E}{\partial \varphi_2} = -\mathrm{sign}(\dot{\varphi}_2)T_2 \end{cases} \tag{10}$$

where T_1, T_2 are the input and output mechanical torque on the input and output shafts, respective,

$$\frac{d}{dt}\left(\frac{\partial E}{\partial \varphi_1}\right) = \left(J_1 + m_B l_1^2\right)\ddot{\varphi}_1 + m_B l_1 l_2\left[\ddot{\varphi}_2\cos(\varphi_1 - \varphi_2) - \dot{\varphi}_2(\dot{\varphi}_1 - \dot{\varphi}_2)\sin(\varphi_1 - \varphi_2)\right] \tag{11}$$

$$\frac{\partial E}{\partial \varphi_1} = -m_B l_1 l_2 \dot{\varphi}_1 \dot{\varphi}_2 \sin(\varphi_1 - \varphi_2) \tag{12}$$

$$\frac{\partial E}{\partial \varphi_2} = m_B l_1 l_2 \dot{\varphi}_1 \dot{\varphi}_2 \sin(\varphi_1 - \varphi_2) \tag{13}$$

Finally we obtain the relations

$$\begin{cases} \left(J_1 + m_B l_1^2\right)\ddot{\varphi}_1 + m_B l_1 l_2 \cos(\varphi_1 - \varphi_2)\ddot{\varphi}_2 = T_1 - \dot{\varphi}_2^2 \sin(\varphi_1 - \varphi_2) \\ m_B l_1 l_2 \cos(\varphi_1 - \varphi_2)\ddot{\varphi}_1 + \left(J_2 + m_B l_2^2\right)\ddot{\varphi}_2 = \dot{\varphi}_1^2 \sin(\varphi_1 - \varphi_2) - sign(\dot{\varphi}_2)T_2 \end{cases} \tag{14}$$

With notations

$$\Delta = \left(J_1 + m_B l_1^2\right)\left(J_2 + m_B l_2^2\right) - m_B^2 l_1^2 l_2^2 \cos^2(\varphi_1 - \varphi_2) \tag{15}$$

$$\Delta_1 = \left(J_2 + m_B l_2^2\right)\left[\mathrm{T}_1 - \dot{\varphi}_1^2 \sin(\varphi_1 - \varphi_2)\right] - m_B l_1 l_2 \cos(\varphi_1 - \varphi_2)\left[\dot{\varphi}_1^2 \sin(\varphi_1 - \varphi_2) - sign(\dot{\varphi}_2)T_2\right] \tag{16}$$

$$\Delta_2 = \left(J_1 + m_B l_1^2\right)\left[\dot{\varphi}_1^2 \sin(\varphi_1 - \varphi_2) - sign(\dot{\varphi}_2)T_2\right] - m_B l_1 l_2 \cos(\varphi_1 - \varphi_2)\left[T_1 - \dot{\varphi}_2^2 \sin(\varphi_1 - \varphi_2)\right] \tag{17}$$

the relations 14 can also be written in the form

$$\begin{cases} \ddot{\varphi}_1 = \dfrac{\Delta_1}{\Delta} = \ddot{\varphi}_1(\varphi_1, \varphi_2, \dot{\varphi}_1, \dot{\varphi}_2) \\ \ddot{\varphi}_2 = \dfrac{\Delta_2}{\Delta} = \ddot{\varphi}_2(\varphi_1, \varphi_2, \dot{\varphi}_1, \dot{\varphi}_2) \end{cases} \tag{18}$$

With notations $y_1 = \varphi_1$; $y_2 = \dot{\varphi}_1$; $y_3 = \varphi_2$; $y_4 = \dot{\varphi}_2$ it is obtained the following relations

$$\begin{cases} \dot{y}_1 = y_2 \\ \dot{y}_2 = f(y_1, y_2, y_3, y_4) \\ \dot{y}_3 = y_4 \\ \dot{y}_4 = g(y_1, y_2, y_3, y_4) \end{cases} \tag{19}$$

with initial conditions

$$t_0 = 0 \, ; \; y_1(0) = y_2(0) = y_3(0) = y_4(0) = 0 \tag{20}$$

SIMULATION SCHEME

Simulation scheme of mechanical transmission is presented in figure 2. It is composed from input shaft, linkage mechanism, unidirectional mechanism and output shaft [8], [9], [10]. Simulation was made by two distinct ways:

1 - by actuating with prime mover with constant speed ω_1;

2 - by actuating with prime mover with constant torque T_1.

The main characteristics of operation by actuating with prime mover with constant speed are presented in Figures 4, Figure 5 and Figure 8a. The main characteristics of operation by actuating with prime mover with constant torque are presented in Figure 6, Figure 7 and Figure 8b. Time variation of load is presented in Figure 3. Simulations was made with the following initial data: $\omega_1 = 1500 rev/\min$; $T_1 = 20Nm$; $l_1 = 30mm$; $l_2 = 70mm$; $l_3 = 100mm$; $l_4 = 100mm$; $l_5 = 100mm$; $J_1 = 1kgm^2$; $J_4 = 10kgm^2$; $m_D = 5kg$;

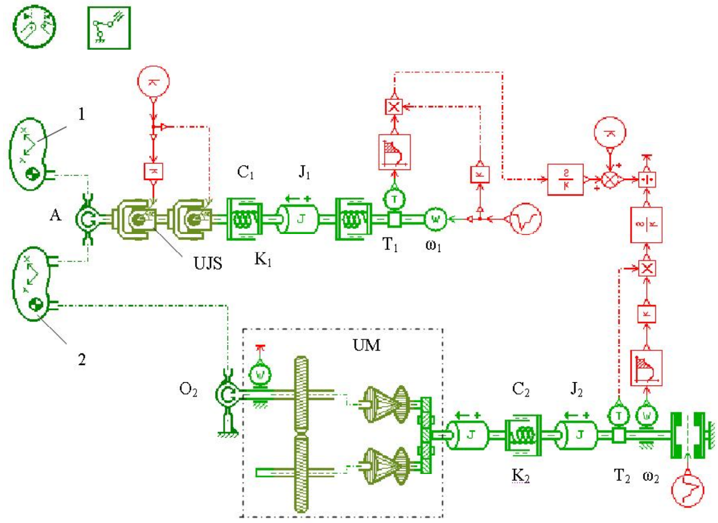

Figure 2. Simulation scheme of torque converter

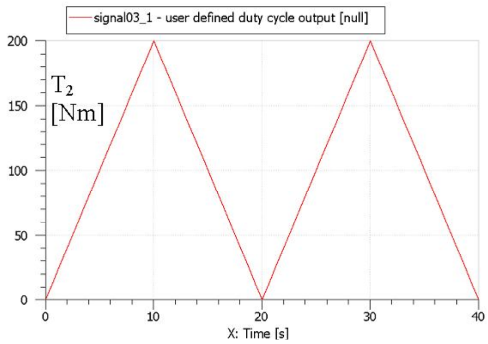

Figure 3. Time variation of load (output torque T_2)

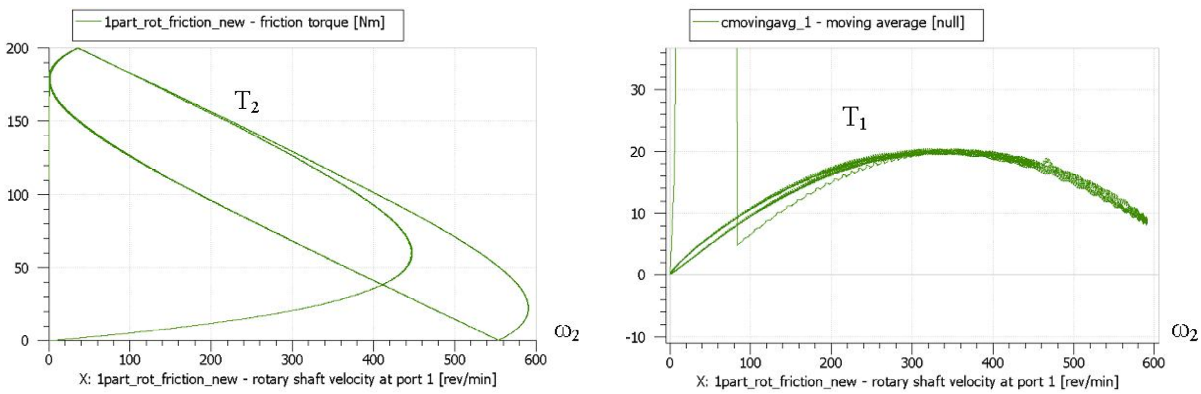

Figure 4. Torques variation T_2 and T_1 depending on the output speed ω_2

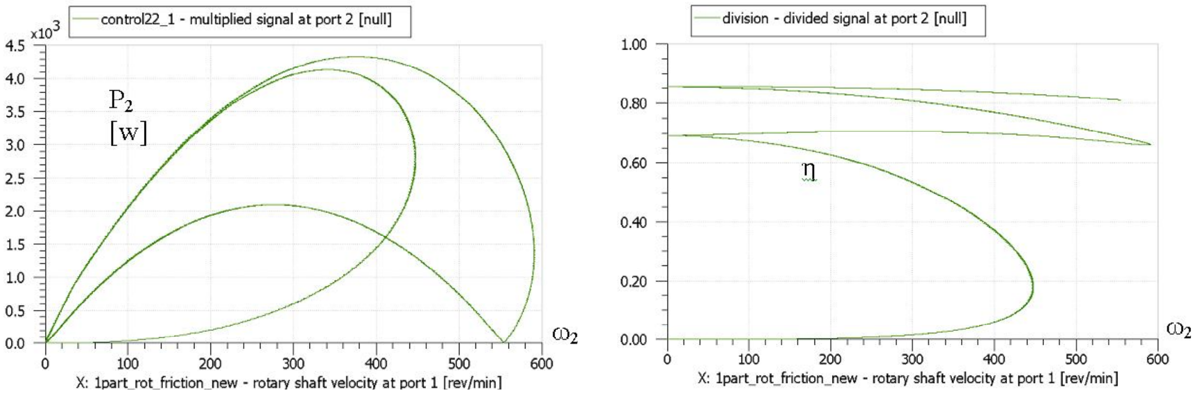

Figure 5. Output power P_2 and efficiency η variation depending on the output speed ω_2

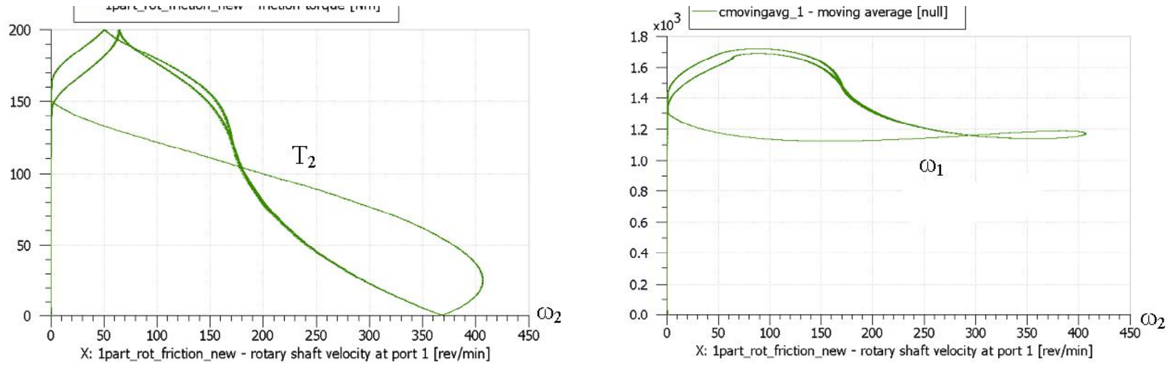

Figure 6. Output Torque T_2 and input speed ω_1 depending on the output speed ω_2

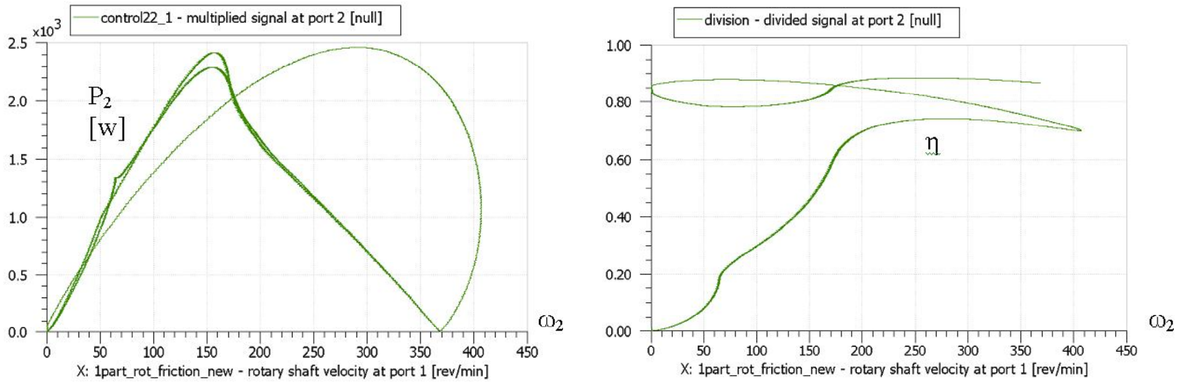

Figure 7. Output power P_2 and efficiency η variation depending on the output speed

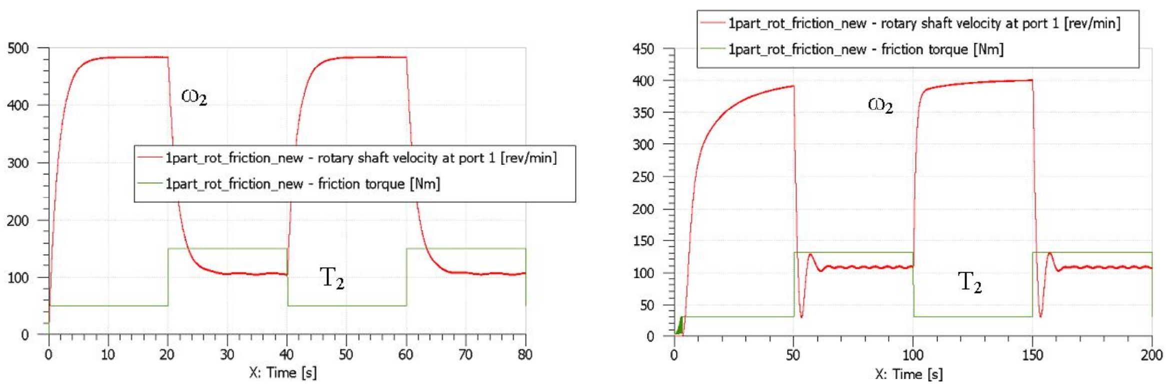

Figure 8. Output speed ω_2 variation to square variation of output torque T_2

a) for prime mover with $\omega_1 = const.$; b) for prime mover with $T_1 = const.$

CONCLUSIONS

From the analysis of the above charts it is noticed major differences between operation with the loading in ascending sequence and the operation in descending sequence of loads. These differences increase with increase of moments of inertia J1 and J2. The maximum power is transmitted to the median speed of the output shaft.

REFERENCES

[1] Jalon, J., G., Bayo, Ed., *Kinematic and Dynamic Simulation of Multibody Systems: The real-Time challenge,* Spring-Verlag, New-York, 1994.
[2] Hartenberg, R., S., Denavit, J., *Kinematic Synthesis of Linkages,* McGraw-Hill Book Company, London, 1964.
[3] Erdman, A., G., Sandor, G., N., *Mechanism design,* Prentice-Hall, Upper Saddle River, NJ, 1984.
[4] Kane, T., R., *Analytical elements of mechanics,* Vol. 1, Academic Press, New York, 1959.
[5] Wilson, H., B., Turcotte, L., H., Halpern, D., *Advanced mathematics and mechanics applications using MATLAB,* Chapman & Hall/CRC, 2003.
[6] Strang., G., *Introduction to Applied Mathematics,* Cambridge Press, 1986.
[7] Gill, P., E., W., Murray, M., Wright, *Practical optimization,* Academic Press Inc., London, 1981.
[8] Guerlet, B., Valéo: *Modeling of Complex Systems with Applications in Automotive Transmissions,* European AMESim Users' Conference, Paris, May 26th 2000.
[9] Lebrun, M., Richards, C., W., Imagine: *How to Create Good Models Without Writing a Single Line of Code*, Fifth Scandinavian International Conference on Fluid Power, SICFP'97, Linköping Sweden, May 28-29 1997.
[10] Doebelin, O., *System Dynamics Modeling and Response,* Friedrich Vieweg & Sohn Verlag, Wiesbaden, 2006.