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Numerical Simulation of the Group of Actuating Diesel Engine – Torque Converter

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Abstract

Hydraulic transmissions are widespread in engineering due to their advantages: easy start, flexibility, simplicity, damping vibrations. These drives can meet to the operating systems of drilling rigs and intervention when they are powered by diesel engines, but also to certain transmissions in the petrochemical industry. The article deals with the numerical simulation of a group of actuating (diesel engine – torque converter), using the Simulink modeling opportunities. Virtual model of the transmission allows the study of the link with the actuated system, aiming the adaptation to the modifications of load and the changes of throttle.

Key words: *torque converter, Simulink*

Introduction

The torque converter is a hydrodynamic transmission, consisting of a centrifugal pump, a hydraulic turbine and a steering device. The torque converter operation is based on the transmission fluid from the pump rotor to the turbine through the steering device, which is fixed (jointly with housing). Steering device (reactor or stator) is to direct fluid entering the turbine rotor to a favorable angle and to transform hydrostatic energy in hydrodynamic energy. This additional element causes a change in momentum to the turbine rotor. The fundamental equation of torque converter is the mathematical correlation developed between the torques of transmission components:

$$M_P + M_{AD} = M_T \quad , \qquad (1)$$

where M_P is the torque for the pump rotor, M_{AD} –torque for the steering device and M_T –torque for the turbine rotor. One observes, that torque converter change the moment of the engine, being used especially in training machines with high inertia. Hydrodynamic transmissions are advantages [3]:

- It ensures easy starting of the machine; the flexible link allows fluid to start the engine idle; the car reached the rated working gradually over time; the easy starting means implicitly a protection of the actuated machine, for example an electric motor is avoid overheating;
- Vibration of the engine system and vice versa are redeemed within the hydraulic transmission;

- Flexible connection between primary and secondary engine provides the possibility of adapting to the requirements of the working machine;
- Ensure the slip, a kinematic chain protection to destroy evidence if bottlenecks;
- Construction is simple and poses no particular problem related to cooling, balancing, maintenance;
- Purchase and maintenance costs are reduced, compared with hydrostatic transmissions.

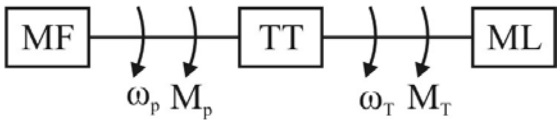
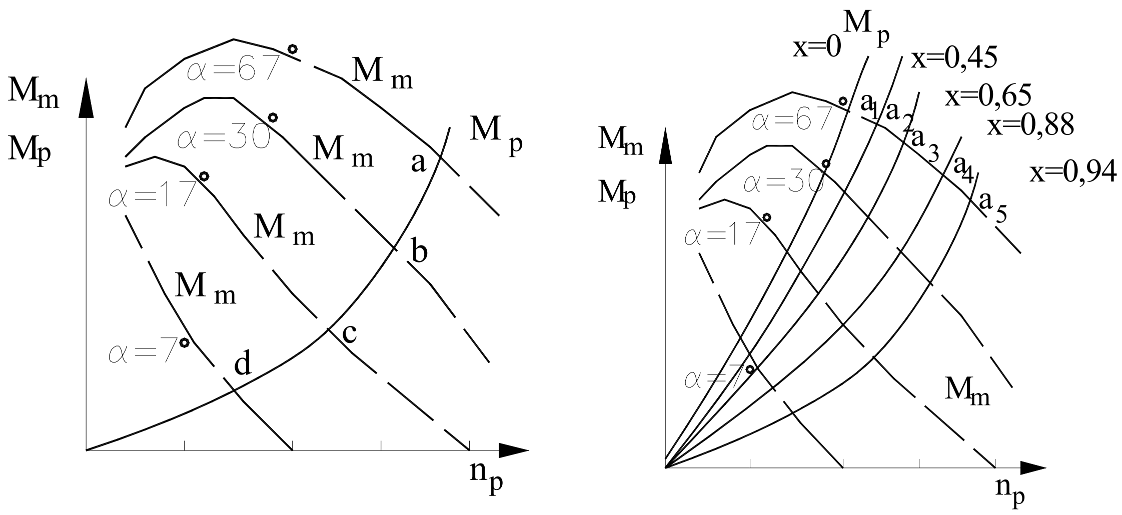


Fig. 1. Transmission scheme with torque converter (hydrodynamic torque amplifier): MF –actuator, TT – torque converter, ML – working machine; ω_P – angular velocity of the pump; ω_T – angular velocity of the turbine, M_P – momentum at the pump, M_T – at the turbine.

The torque converters coupled with energy sources are treated in numerous technical books, the considerations listed below have the role to present shortly how to make the link between actuator and work machine Fig. 1, through a torque converter. We exemplify the case of an internal combustion engine. The transparency of hydrodynamic torque amplifier has an important influence over the coupling. Due to the changes of the load at the output of the rotor of turbine, a nontransparent torque amplifier causes to the engine small variations of load compared to the transparent type.



a b

Fig. 2. Torque converter coupled with the internal combustion engine:
M_p – momentum of the pump; M_m – momentum of the internal combustion engine; n_P –speed of the pump; α – the angle of throttle; *x* – coefficient of transmission.

In fig. 2,*a*, a hydrodynamic transparent torque converter, because its insensibility to the speed of the pump shaft, is represented by a single curve and torque curves will follow different variation, depending on the angle of the throttle opening. Points of running will be only one on each characteristic of engine *(a, b, c, d*). To the transparent torque converters (direct transparency) Fig. 2,*b* their input characteristic is represented by a family of curves for different values of transmission coefficient; transmission coefficient is defined as the ratio:

$$x = \frac{\omega_T}{\omega_P}, \quad (2)$$

where: ω_P is angular velocity of the pump, ω_T – angular velocity of the turbine. For the same throttle opening α, there will be a lot of operating points a_1, a_2, … .

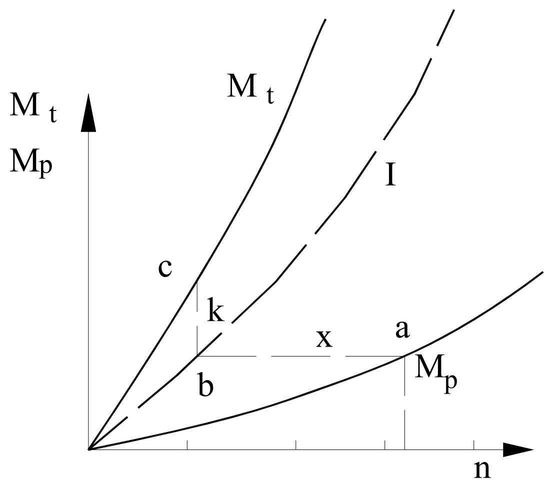


Fig. 3. Change of the momentum within torque converter.

When the engine is starting (x = 0) for α = 67 ° angle of opening of the engine throttle, the balance point of entry moment is a_1. When the turbine speed increased, to x = 0.45, the equilibrium point will be a_2, which is realized at higher engine speeds. The transmission of torque to the rotor of turbine is held in accordance with the relationship expressing the transforming of moment in torque converter [3]. This is highlighted by Fig. 3, where the shift of characteristic from input to output occurs through an imaginary parabola, which represents the variation of torque at the conversion rate of momentum defined as:

$$k = \frac{M_T}{M_P}, \qquad (3)$$

with k = 1. Between points a and b there is a speed ratio equal to x and a transformation ratio k = 1. Between points b and c there is a speed ratio x = 1 and a transformation ratio of momentum equal to k.

Numerical Modeling

Based on the theoretical model presented in the introduction, in the library of Simulink there is a block like a torque converter (virtual model), *Torque Converter*, block represented in Fig. 4. This element can be set to function like a particular torque converter using the producer data. Along with it were introduced as key elements for modeling: a virtual diesel engine, *Diesel Engine* and two gear transmissions *Simple Gear*.

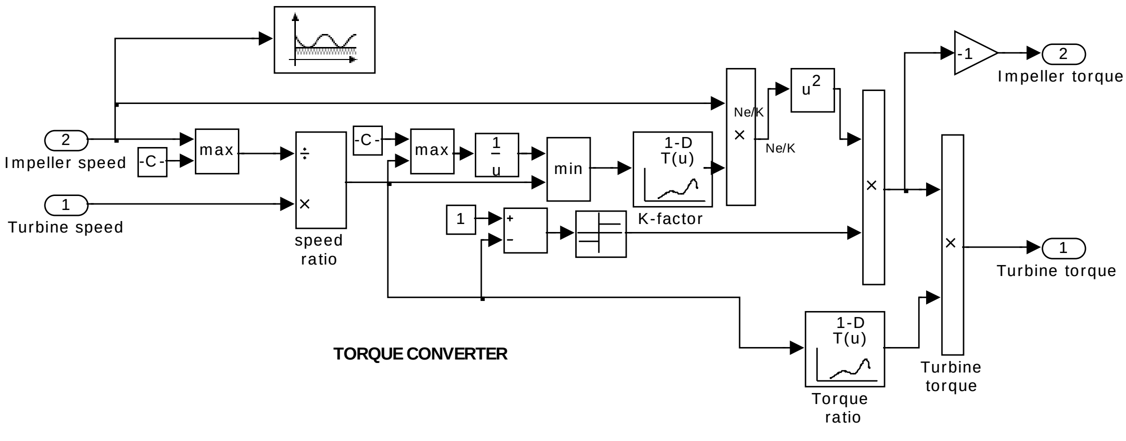


Fig. 4. The model of torque converter (Simulink library).

Scheme of Fig. 5 is explained below. *Signal Builder* block is used to speed up diesel engine (*Diesel Engine* block). This signal is physically equivalent with the engine throttle opening at different times (for instance 0.5 represents a 50 % opening at the time specified in the construction diagram of the signal). The driveline environment block *Env* specifies the global information and connects the solver that our model needs before we can begin simulation. Mass moments of inertia of the moving elements between of the engine and torque converter and between torque converter and machine work were introduced in blocks: *Inertia 1* and *Inertia 2*.

Initial speed of the engine block is given by IC (*Initial Conditions*). It was considered an application of hydraulic transmission: the training of a rotary tables of drilling a water rig, where the kinematic chain is the engine – torque converter - gear transmissions. Rotary table torque can be expressed by a relationship of the form [1]:

$$M = M_1 + M_2 + M_3 \quad , \tag{4}$$

where torque at the bit, for deployment of rock is:

$$M_1 = 0.067 G_s D_s \, . \tag{5}$$

Torque consumed by friction to bit is:

$$M_2 = 0.08 D_s^{1.5} \, , \tag{6}$$

and friction torque corresponding to the friction of drilling string in the hole is:

$$M_3 = 2.1 \rho L \tau \tag{7}$$

Recommended speed to the rotary table is given by:

$$n = 200 - 150\tau \, . \tag{8}$$

Opposing torque at the working machine is built as a signal given by the theoretical relationship (rel 4-7) introduced in an user-defined function *Rotary Table Torque,* on the parameters (block *Drilling parameters* Fig. 6): diameter of bit D_s; depth of hole L; weight on bit G_s; point where we stand with drilling (0 for start of the hole and 1 for end of the hole) τ; density of drilling fluid ρ. Opposing torque is introduced by the instrument *Torque actuator* and displayed in block *Working machine torque*. To display the engine speed and the working machine using sensors *Speed sensor* 1 and *Speed sensor* 2. Signals of these blocks will be seen in the display: *Angular Velocities Engine & Rotary Table.*

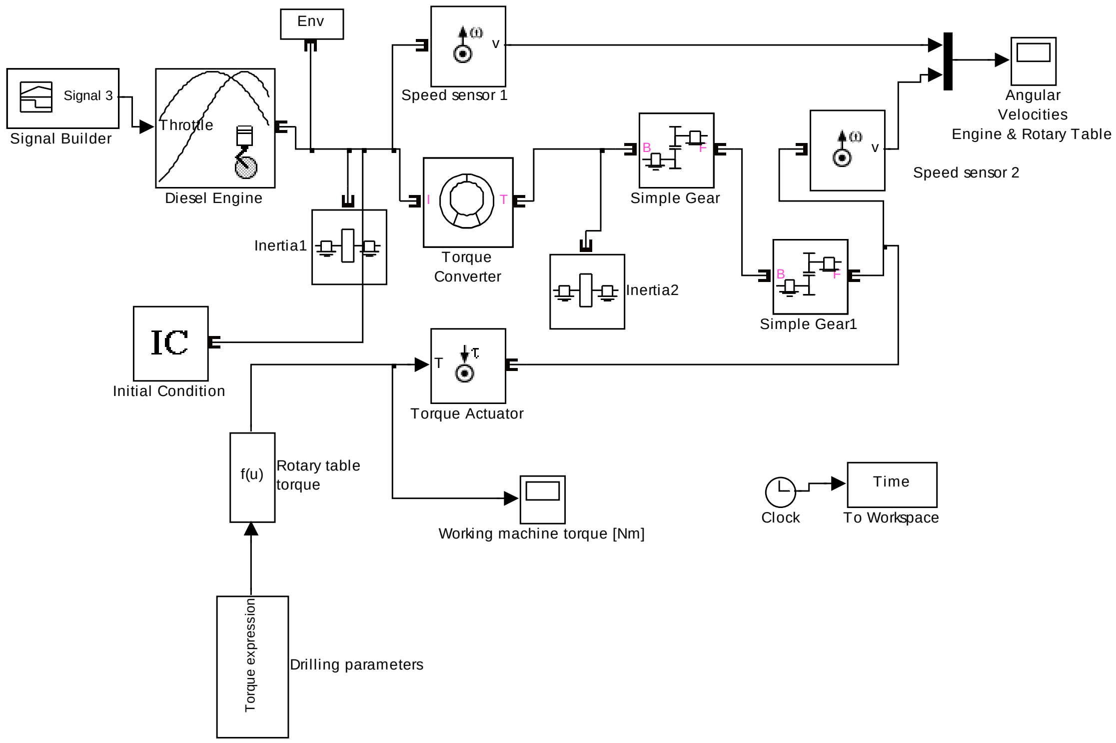


Fig. 5. Modeling of the operation of torque converter: actuating of a rotary table.

Results and Conclusions

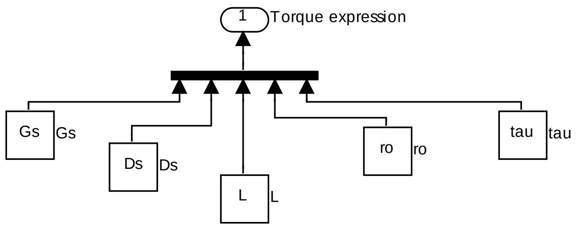
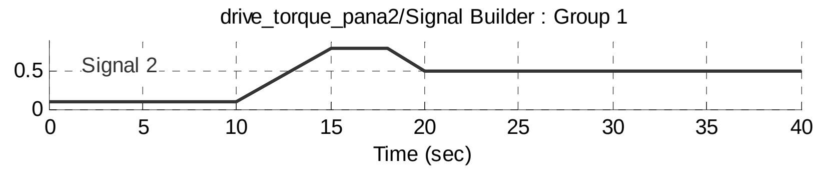


Fig. 6. Torque dependent parameters of rotary table, block *Drilling parameters*.

Numerical modeling for engineering applications is a practice that has spread and is used for teaching in universities but also in designing applications involving large expenditures to achieve a physical model [2]. If of the point of view of sizing application, 4-8 relations used in the most unfavorable conditions allow the choice of drive power, drive on a virtual model study cover all situations that can be imagined functional operation. For example in Fig. 7 and 8 have been imagined two work situations imposed by a certain torque at the rotary table and the mode of acceleration of the diesel engine.



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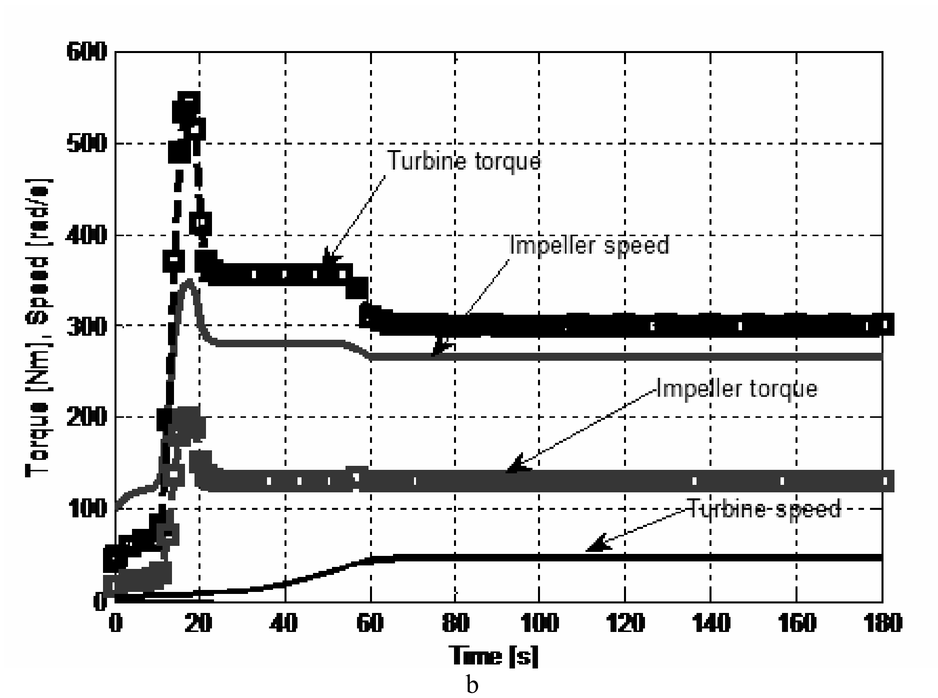
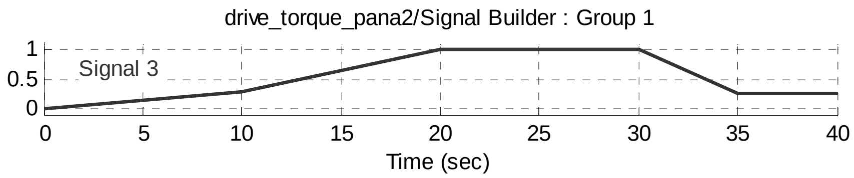


b

Fig. 7. Transmission operation with torque converter: a) the mode of acceleration of the diesel engine b) changes to the turbine and pump torques and angular speeds appropriate.

In fig. 7 it appears that the acceleration of the engine in the range of time 10 to 20 s, increases the torque at the pump and turbine, after which the throttle setting to 0.5 determine the stabilizing of the moments, the torque to pump faster, the slower to the turbine in 60 seconds. Torque is sufficient to ensure the turbine angular velocity 50 rad/s. For the control signal of Fig. 8,*a* 30 seconds after the engine deceleration and throttle setting to 20 % of the maximum opening is insufficient for "execution" task and the turbine is blocked.



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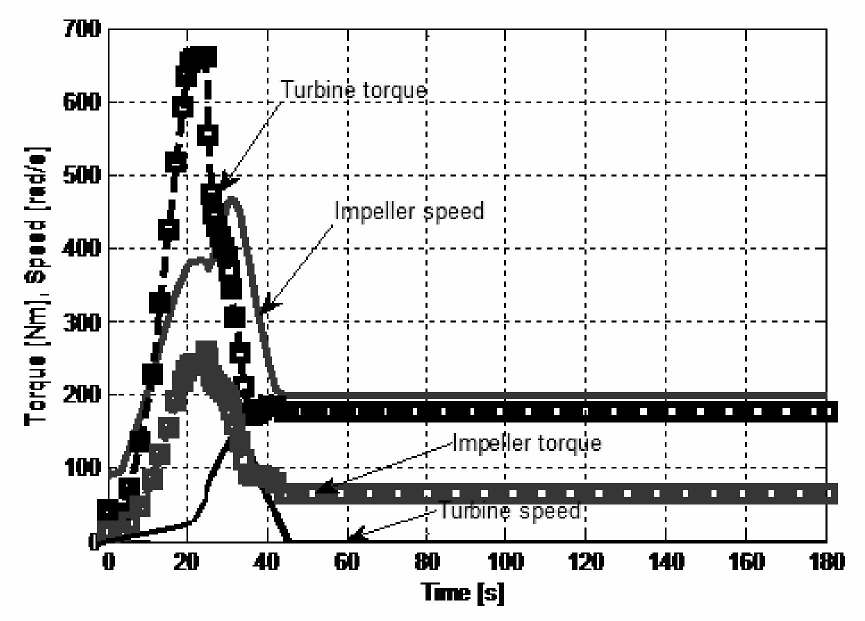

b

Fig. 8. Transmission operation with torque converter and turbine blocked: a) the mode of acceleration of the diesel engine b) changes to the turbine and pump torques and angular speeds appropriate.

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Simularea numerică a unui grup de acţionare motor diesel turbotransformator

Rezumat

Transmisiile hidraulice sunt larg răspândite în inginerie datorită avantajelor pe care le au: pornire uşoară, flexibilitate, construcţie simplă, amortizarea vibraţiilor. Aceste acţionări pot fi întâlnite în cadrul instalaţiilor de foraj, atunci când acestea sunt acţionate de motoare diesel, dar şi la anumite transmisii din industria petrochimică. Acest articol se ocupă cu modelarea numerică a unui grup de acţionare (motor diesel– turbotransformator) utilizând posibilităţile de modelare din Simulink. Modelul virtual al transmisiei permite studiul legăturii cu maşina de lucru, urmărind adaptarea la modificarea sarcinii şi a modului de comandă (accelerare) la motor.