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A Two Stream Modelling Method for Drive Systems as in the Case of Tractor Differential Mechanism Model

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Abstract- In this paper, the "two stream" modelling method of a power transmission system is described. This method bases on basic dynamic principia with feedback effects in dynamic systems. Authors presented other approach to modelling of the driving systems with motors and power trains for power transmission. Instead of the, commonly used, power flow authors use speed and force flow going in opposite directions. In one method the speed is the engine output signal that is flowing through serially connected blocks. This speed signal is processed in the block and passed to the next one. Each of the blocks responds with force in respect to its movement speed and external load. This force is sent back to the previous block in motor direction. All blocks have similar structure with the same basic input and output signal of speed and force. Some additional signals can be added for control or to add the additional load coming from an external system to the power transmission system. The relation that is joining the dynamic (forces or torque) and kinematic signals (speed, displacement or angle) are tensions or torsions. The structure of the basic blocks with torsion, friction and inertia is presented. In this paper the other opposite model with torque as the output and speed as the input signals of motor was also presented. This methodology seems to be in accordance with real running processes and it is quite easy for an application. It is especially destined for students teaching for presenting the relation between elements and feedback effecting. As the example of usage the methods authors present model of tractor differential gear model what is one of the most complicated elements of the tractor for modelling. The results of the tractor's run simulation were in accordance with real test results.

***Keywords*:** power transmission system modelling, speed and force flow, dynamic process, agriculture tractor differential mechanism model

1. Introduction

The analyses of dynamic processes with computer tools became a standard step in procedure of machine designing and verification process. There are many computer programs that make these tasks easier and faster. In the propelling system we can consider so many phenomena corroborating the fact that it is impossible to build a universal model. However, we can find many specialised tools for verification of our design. Another role of modelling is to help the designer to understand how systems works, how the energy flows from the engine through the transmission chain to e.g. wheels. Some programs offer readymade "libraries" of typical elements that can be joined together like in a block diagram and give the result of the simulation as it is shown Web-1. Designers only have to insert the right parameters of modelled devices. This approach in modelling is not efficient in education process, because it is hiding all the equations, relations between elements from the designer. When you are well trained and you understand what is going on behind such a model, you can really act very efficiently. If not, you can try to set parameters of systems elements by trial and error method.

In order to analyse a complicated system such as an **agriculture tractor system,** the “two stream model” has been used where two streams: speed and torque, flow in opposite directions through a driving chain from the engine to the wheels.

The proposed terminology is “two stream model” where two streams: speed and torque flow in opposite directions through driving chain from engine to wheels. Authors were forced to do it because they could not find modelling tools that would give the simulation result similar to the result of the experiment. This modelling method has been developed and systemised for student education and seems to be quite easy and shows that it can be used for modelling of quite complicated, not only propelling, dynamic systems based on simple dynamic principia.

2. Power transmission system models

The typical power transmission system consists of: motor, power transmission train with: clutch, gearboxes, some energy dividing devices, wheels etc. In a simplified form, this power transmission chain can be modelled with serial structure shown in fig 1, what can be used for a straight run of the vehicle on the same surface under wheels (Szlagowski 2010).

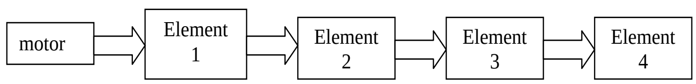

Fig. 1. The example of simplified power flow in serial structure system

The power flows in one direction: from motor through elements 1 to 4. In such a model the initial power is decreased by power loses in each element. So the power coming to the last element equals: power of a motor multiplied by efficiency of each element. The speed of the system movement depends on combined characteristic of the whole system. The system inertia is the combined inertia of all elements. In reference to electric vehicle the stable car speed (under stable condition) equals: power delivered to the wheel divided by movement resistance. If movement resistance depends on non-linear relationship we have to solve non-linear equation or use graphical form.

This model is still used as the very initial model to present what is going on with power in power transmission chain. But this approach seems to be too simple to help to explain and understand the phenomena running in the system, because in a typical power chain, cooperating elements interact with each other. The motor propels clutch but the clutch effects on the motor with the same torque. Other elements behave in a similar way. The power is flowing in two directions and the model from fig. 1 should be modified to the form presented in fig. 2.

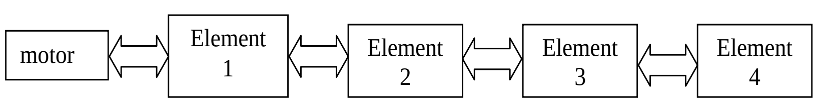

Fig. 2. Two direction power flow model

The problem appears when decision what signals should be used for power transmission description is to be made. According to Newton’s principia the torques flowing between elements are the same so that they balance each other. The speeds (without slip) are also the same.

Each element constitutes part of a basic dynamic system presented in fig. 3. It is typical feedback model (Franklin et al.,2006), where propelling force is compensated by inertia, friction and spring force. We have two parameters that are needed to power calculation: speed and force. We can notice additional phenomena that have influence on system behaviour, it is the spring energy. So we need model, that will base on force/torque and speed flow. Nevertheless in this model, the input parameter is the force and output is the speed.

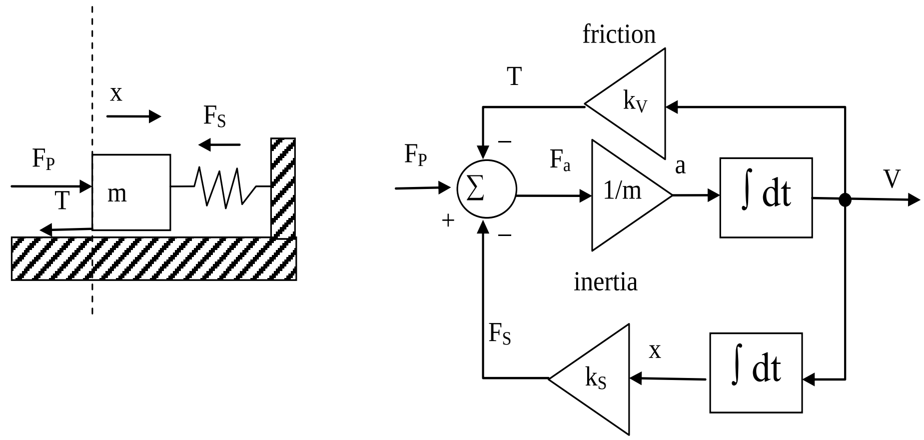

Fig. 3. The model of basic dynamic system.

The difficulty can appear when we want to join elements whose models should be built in the similar way. That means: each of them should have the same input and output signals. The speed and force/torque were chosen as the input and output parameters. In the proposed approach to model building, the motor generates speed in reference to the load given by the next element. The speed is determined in accordance to motor characteristic ω(M). The speed flows to the next elements that answer with the load-torque. This torque is passed to the previous element where it is summed with its load and passed father towards the engine direction. Such a model was called "two streams model".

3. Two streams models

The structure of two streams model is shown in fig. 4. In fig. 4b we can see the typical feedback structure.

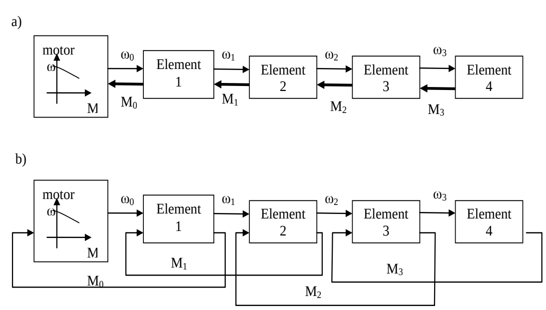

Fig. 4. Two streams model a) input and output of block on both sides, b) input and output of block on one side

This model seems to be natural, because:

- The speed is the same in whole propelling system excluding gear box and slips.
- The motor propelling torque depend on the load – motor without load can't produce propelling load, although is running with maximum speed.

So it is called two streams mode type V.

The model of a basic transmission element is shown in fig. 5. It consists of following block:

- Inertia represented by gain 1/m block
- Friction that depend on speed (this block is modelling static and kinetic friction)
- Elasticity of twisted elements presented by gain $\mathbf{k_x}$ block (coefficient of elasticity)
- Backlash.

From the input speed ($\mathbf{V_I}$) the output speed ($\mathbf{V_O}$) is subtracted and the result is integrated. The integration result passes through backlash block that gives the spring deformation x. This deformation results in (or it is caused by) the force $\mathbf{F_S}$. This force also corresponds to the output force F_O. This force is summed with the input force (with proper sign) and the result ($\mathbf{F_N}$) goes to friction block. In this block the $\mathbf{F_N}$ force is reduced by friction. The friction depends on movement speed. So, when the friction is equal or higher than $\mathbf{F_N}$ the $\mathbf{F_a}$ force can be equal to zero or change the sign. The $\mathbf{F_a}$ force propels inertia with an acceleration **a**. The integration of the acceleration gives output speed V_O. In this block some simplifications were done like assumption of integrations constants equal zero.

The model of basic transmission element is shown in fig. 5.

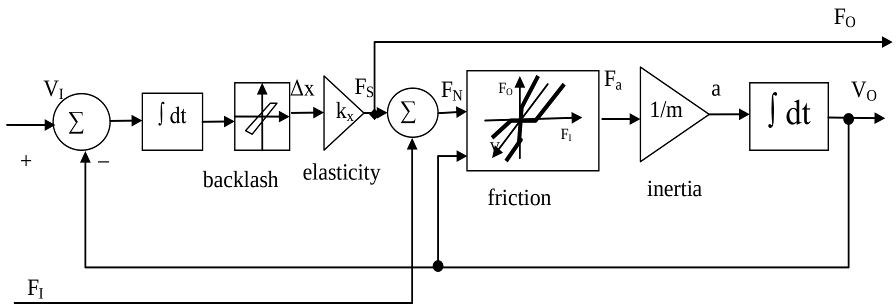

Fig. 5. Model of a basic transmission element

Some modifications of this model are required. The integration of the displacement must be resettable in the clutches as well as the speed and torque ratio should be added in the gearbox. But the basic rules must be the same. In addition, some simplifications should also be done.

Fig.6. shows the model with simplification of the friction model, which depends on speed in linear function.

Another problem that can appear with motor model is connected with characteristic in the start of the movement stage. To avoid this problem, a mechanical part of the engine should be modelled like the other basic elements.

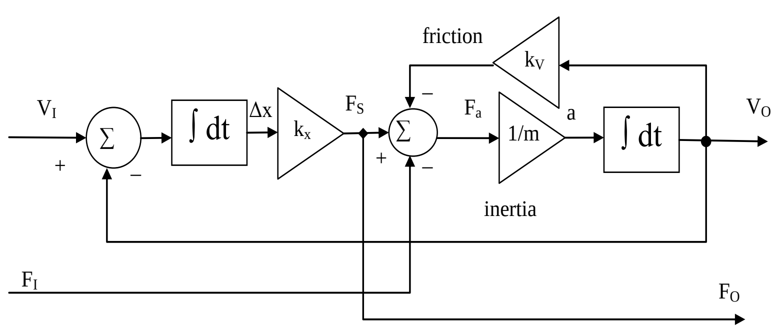

Fig. 6. Simplified model of basic element for V type model

The above description consider model, in which the speed was the output and force/torque was the input value of the engine. In some cases the more natural approach is the opposite one, i.e. when force/torque is an output signal. Such a model (called type M) of the system is presented in fig. 7.

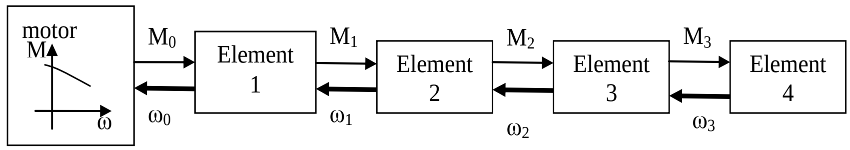

Fig. 7. Two streams model with torque as an engine output value

The basic rules in both models are the same. Each element should have similar structure and the same output and input signals. The main idea (simplified structure) of a model of the basic element is presented in fig. 8. It is very similar to model presented in fig. 3.

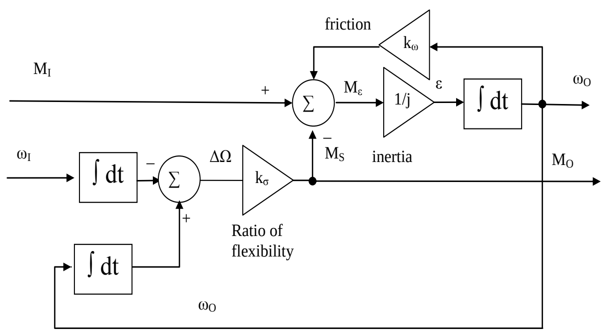

Fig. 8. Basic element for model type M

This methods proved to be effective for modelling quite complicated systems. The k_σ that play important role in conversion of a displacement to a force/torque don't need to be set very accurately (when we are not interested in displacement modelling).

The equation of state and variables of state can be found basing on graphical model.

In controlled elements we can have additional steering input, for instance a signal what controls switches that change the block's internal structure or parameters.

As an example of the methods usage the model of agriculture tractor with differential mechanism will be presented.

4. Two streams tractor model

Basing on presented methodology the model of agriculture tractor was built with Matlab/Simulink software. The general structure of tractor model is presented in fig. 9. The motor drives power transmission chain with wheels, which are cooperating with ground producing forces that propel the tractor body and agriculture tools. (Zebrowski 2006)

It is not uncommon for the tractor to ride with left and right wheels on different types of ground. In such cases some new phenomena like tractor turning can appear. So it is necessary to have a model of differential gear. This model was built in accordance with the methodology described above.

The differential block is one of the most complicated (right behind the wheel cooperating with ground) element because of 3 inputs and 3 outputs.

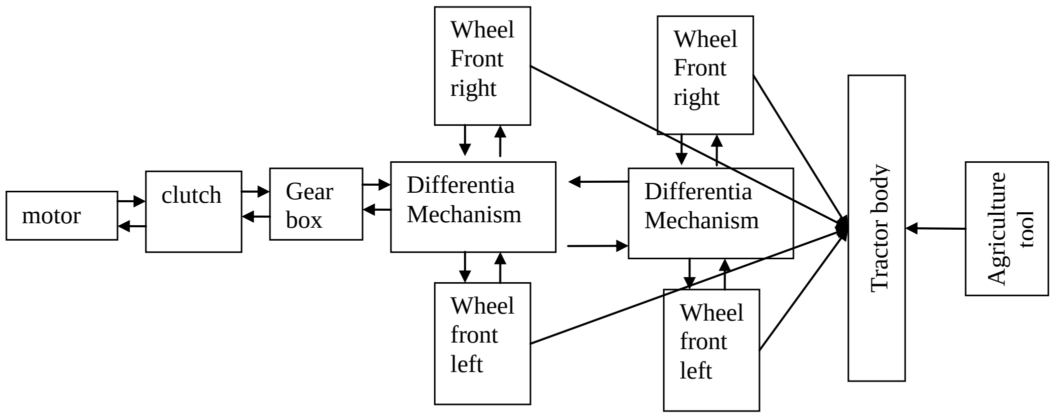

Fig. 9. The concept of speed and torque flow in the stream model of agriculture tractor

The differential gear model built of basic "Simulink" elements like: gain, sum, and integrator is presented in fig. 10.

In the presented model the input signals are: **LR (LR)** load of side shaft (right,/left), **Vin** pinion shaft speed and block signal. The output signals are: **MlooadF** – load of pinion shaft and **VR** and **VL** the rotation of right and left shafts. Rectangles divides model into part of right and left shaft and satellite.

The pinion is rotating with Vin speed and its rotation is passed via gear pinion-ring gear to satellite-shaft gear where rotation of ring and satellite sum up to **RR(RL)**. This rotation of shaft gear is compared with shaft rotation and the difference **TRS (TLS)** is multiplied by flexibility coefficient what gives propelling torque **MR (ML**). The difference between this torques **Msat** is propelling satellite and the sum of them is the pinion load **MlodF**. If **Msat** is bigger than satellite friction, satellite stars to ratite and reduce speed of the more loaded shaft.

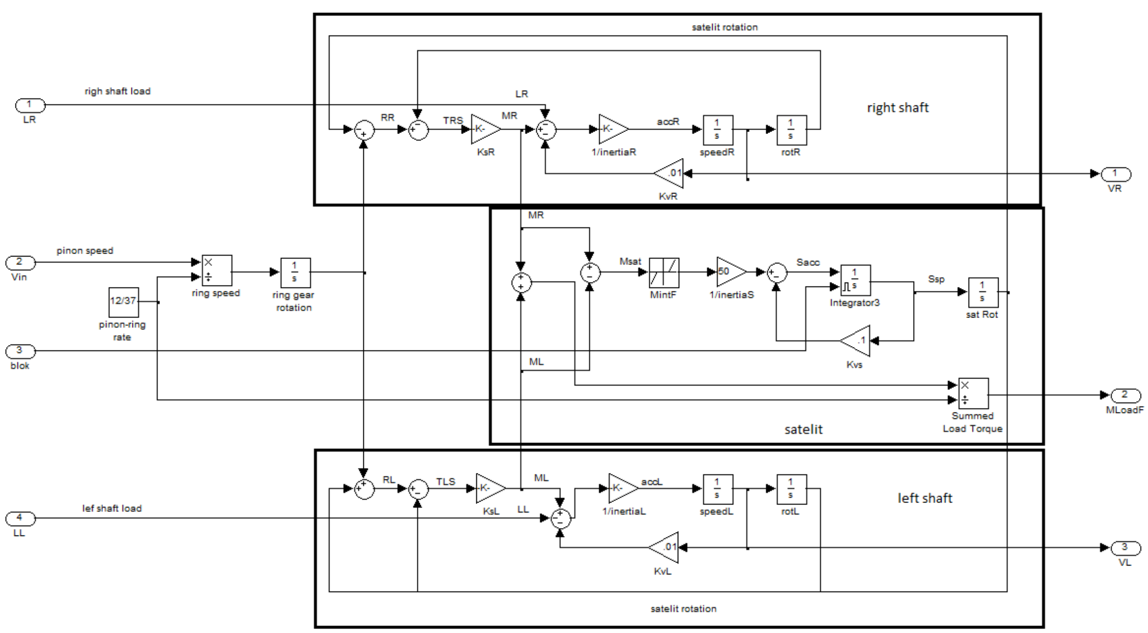

Fig. 10 Example of differential gear model built with basic Simulink elements

5. Model verification

The stream modelling concept was verified by comparing computer model simulation results with the measurement results of the real object trials. Real trials were carried out with 4 wheel drive tractor: URSUS 1204 and both results were in great accordance. During tests the behaviour of tractor with locked and free differential gear were compared. The test scenarios were the same for both trials. Tractor starts running on the field with the same ground under all wheels. After few seconds tractor was running on the field with both sides running on different grounds, what causes different rolling resistance, different wheel slips and different driving forces. The example simulation results are presented in fig. 11. (Zebrowski et al. 2010).

Figures present courses of chosen parameters: driving force of the right and left wheels, load torque of right wheel in the time of trial. The comparison of simulation and real tests results proved that the differential gear should be present in model because it has big influence on tractor behaviors.

The presented differential gear model inbuilt into tractor model results in a high compatibility between simulation and real trials results.

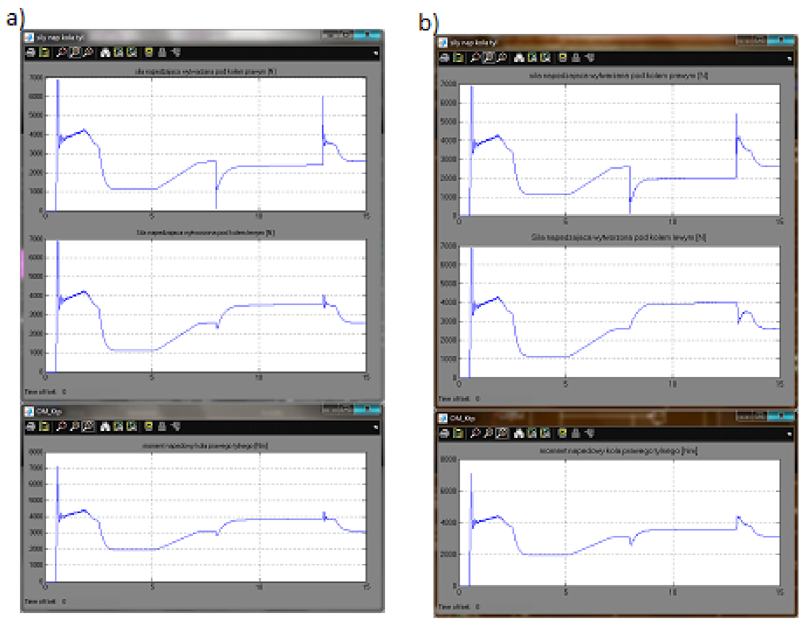

Fig. 11 Simulation results for free a) and locked b) differential gear

6. Conclusion

The two streams modeling method may simplify the model building process, especially for the beginners who want to better understand system behavior and interaction between elements. The type of the model depends on personal preferences.

The presented method has appeared to be quite efficient for creating a propelling system model with no-linear and asymmetric relation.

The presented method based on basic dynamic principia is being used with success for teaching students about modeling. The easy access to all “variables of state” helps to understand how to build the equation of state.

The efficiency of this method has been proved in many models, one of them was the agriculture tractor with differential gear.

References

Franklin G. Powell J. Emami-Naeini(2006) „Feedback control of dynamic System” 5-th edition Pearson Education, Inc

Szlagowski J. (2010) Automatyzacja pracy maszyn roboczych. Metodyka i zastosowania. WKŁ, Warszawa
Żebrowski Z.: 2006 Modeling of coupling front axis drive in wheeled agricultural tractor. The 10th European Conference of International Society for Terrain-Vehicle Systems (ISTVS), "New Developments in Off-Road Vehicles and Machinery" 03 – 06 October 2006. Budapest, Hungary
Żebrowski Z. i inni: (2010) Modelowanie, symulacja i badania mechatronicznych systemów automatyzacji pracy agregatu ciągnikowego. Projekt badawczy własny N 502 010 31/1378, Warszawa 2010

Web sites:
Web-1: http://www.mathworks.com/products/matlab/ consulted 03 Jan. 2015.