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# COMPUTER AIDED DESIGN OF TRANSMISSION POWER SYSTEM OF THE ROAD BUILDING MACHINES

Summary. When designing the power transmission systems of building machines it is necessary to know the dynamic loads.
We can determine these loads by means of simulation calculations on the computers-using computer aided design.
Simulation calculations are carried out for the adequate mathematical models, which change their forms according to the operation condition of the power transmission system.
The program, developed by the author, of such calculations can go into complex CAD program or be a support software for CAD in traditional designing.

## 1. Introduction

When designing the elements of machines it is necessary to know the dynamic loads. Determination of these loads by the traditional design methods is not possible and they are estimated by multiplication of static loads by dynamic loads factor. Then, the results of calculations are verified by the means of measurement on the real object - after the prototype has been produced.
Using computer aided design (CAD), these loads can be relatively precisely determined by the means of digital simulation carried out for properly formulated physical and mathematical models which in case of power transmission systems can change their forms on each phase of their operation, such as: starting, engaging, slip and the like. The description of some elements of such a procedure will be subject of the present paper.

## 2. General algorithm of the method

We can determine the dynamic loads solving an equation of motion of system's elements, including machine structure, taking into consideration external reaction and the factors related to the power transmission system and its control. Solving the equation of motion - the mathematical model, we can also study the other dynamic phenomenon such as loads distribution for the individual driving axles, determine the course of driving force, determine amplitude-frequency charakteristics, study the effect of the factors, we can intersted in, such as e.g. the turn-on time of control clutches - their charakteristics on the value of dynamic loads.

In order to carry out the calculation it is nacessary to know the parameters of mathematical model such as mass moments of inertia, torsional rigidity coefficients, damping coefficients, performance characteristics of engine and hydrokinetic torque converter, etc.

These parameters can be determined already in the design phase. As a general rule, already at the beginning of design we determine the power of machine's driving motor, the characteristic of hydrokinetic torque converter, capacity of bucket, lifting capacity of machine, parameters of tyre and the like.

The other parameters of the model - such as torsional rigidity coefficient - we can determine by means of calculation basing on the known dependences or we can assume on the basic of relative dimensions. General block diagram of the method is shown in Fig.1., while the initial form of physical model - Fig.2.

As it has been already described in the introduction, both physical and mathematical models change their forms on each phase of operation of the power transmission system e.g.: the engaging is followed by the change of physical and mathematical model - reduction of the degree of freedom of the system [5], after the slip of the wheels in relation to substrate the condition of engaging of the power transmission system with the loader's structure change, and the like; therefore in every step of integration the conditions determining the assumption of the model adequate for calculation must be checked. After each change of model it is necessary to verify the angular pathes [5] in order to continue the calculations on the new model.

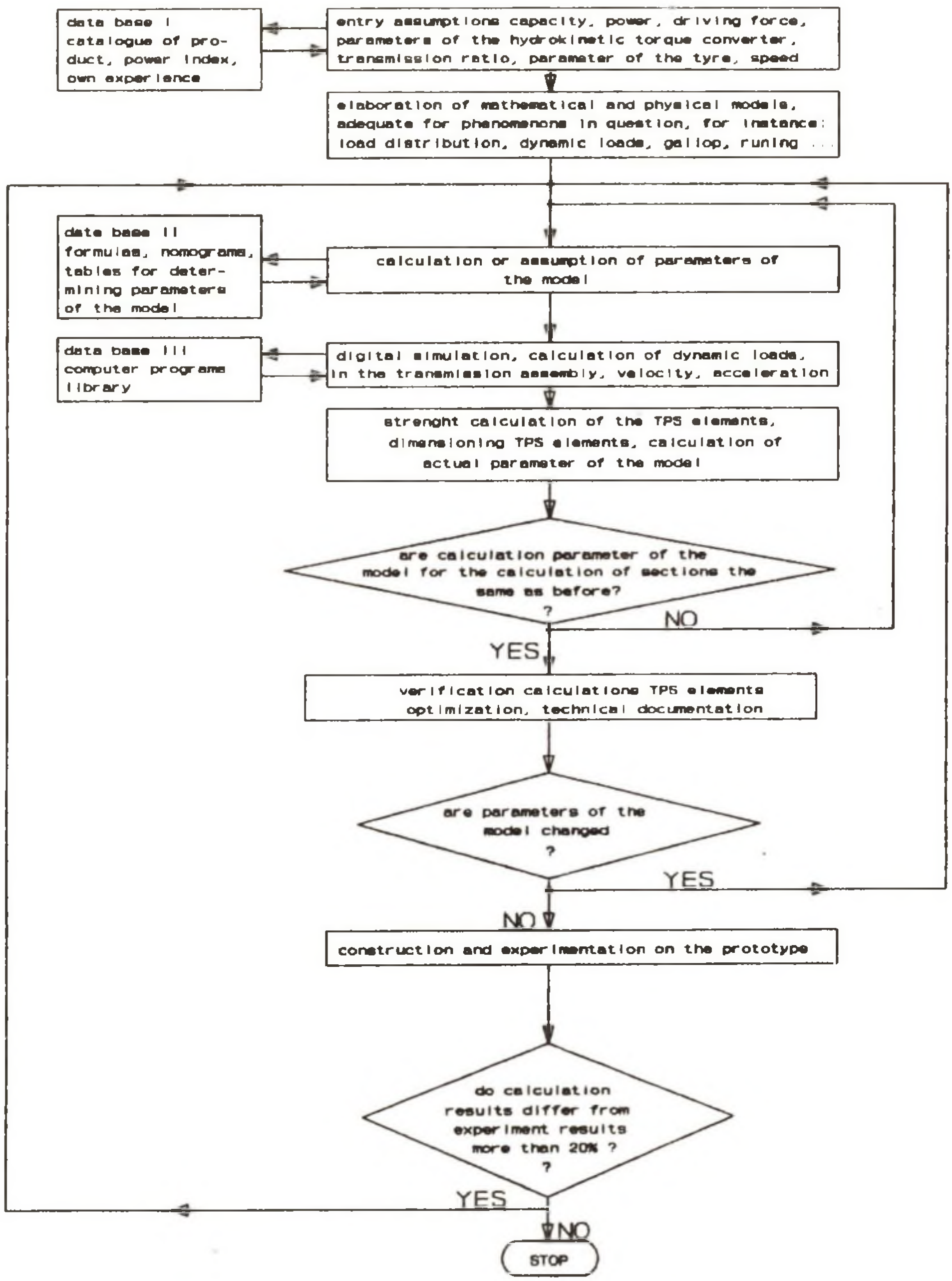


Fig.1. General block diagram of CAD method for power transmission systems of building machine

$M_n(\varphi_0, t) \quad f_M(\varphi_1/\varphi_0)$
$i_d(\varphi_1/\varphi_0)$

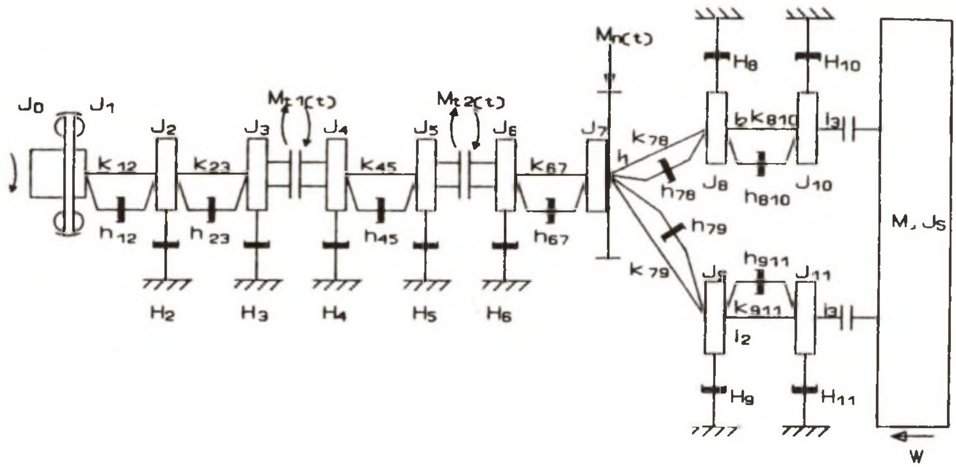


Fig.2. Physical model of loader TPS during start moving by clutching in direction cloutch

## 3. Numerical formulation of selected transient states occurred in power transmission system of building machines

With the change of the form of model the discontinuities of the describing function occur resulting in specific problems concerning their discription. These transient states, such as e.g. engaging, starting, rupture of the wheels' adhesion to substrate and the like, have to be correctly numerically formulated.
Let consider - for ilustration - three cases.

### 3.1. Engaging

In the building machines the hydromechanical power transmission systems, controlled by the multiple-plate friction clutch, are mainly used.
Time $t_0$ - when the clutch plates come into contact (Fig.3) is assumed to be the point of the beginning of engaging (moment of friction $M_t \neq 0$), while time $t_1$ - as the end of engaging when the angular

velocities of active and passive part of the clutch are equal, i.e.:

$$\dot{y}_1=\dot{y}_2 \tag{1}$$

where: $\dot{y}_1$ - angular velocity of the clutch's active part

$\dot{y}_2$ - angular velocity of the clutch's passive part

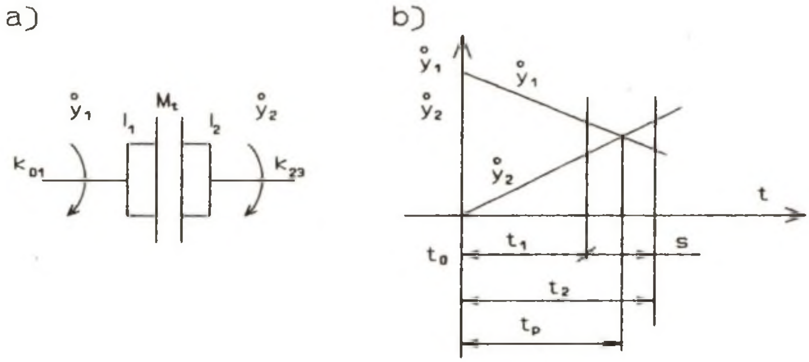


Fig.3. Course of the engaging.

a - physical model

b - determination of the point of engaging

Therefore, when making the integration of differencial equation we have to examine the condition (1) in every step of the integration.

As it is seen from Fig.3, even with the small step of integration of differential equation the "omission" of the point of engaging can happen, i.e. the situation when for:

$$\begin{gathered} t=t_1 \qquad \dot{y}_1-\dot{y}_2>0 \\ \textit{while for} \quad t=t_2: \\ t_2=t_1+S \qquad \dot{y}_1-\dot{y}_2<0 \end{gathered} \tag{2}$$

The system becomes divergent, further calculations are impossible. So, we have to correct the step $S$ of integration. The most effective way consists in it that we halve the basic integration step and examine the difference $\dot{y}_1-\dot{y}_2$ for the time $t_1+S/2$.

If this difference is positive, then we devide the integration step by four and again calculate the difference $\dot{y}_1-\dot{y}_2$ for the time $t_1+3/4S$, etc., till the change of sign occurs. After the change of sign of the difference we halve the last step and substruct from the last time.

We proceed this way till the state of equality of $\dot{y}_1$ and $\dot{y}_2$ is reached, for the assumed numerical accuracy.

3.2. Starting.

The tyred driven wheel is influenced by the basic loads shown in Fig.4.

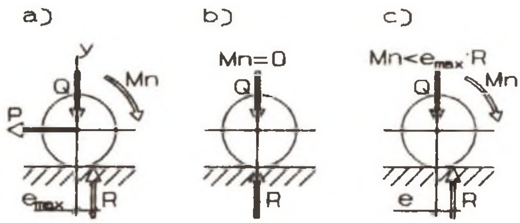


Fig.4. Basic loads influencing tyred driven wheel

From the point of view of interaction of the power transmission system - wheel and loader's structure, we distinguish three basic states:

a) - state of starting when $M_n<R\cdot e_{max}$

b) - state of starting when $M_n=R\cdot e_{max}$

c) - state of motion when $M_n>R\cdot e_{max}$

During starting the arm of rolling resistance torque changes its value from $e=0$ at $M_n=0$ to $e=e_{max}$ at the moment when $M_n=R\cdot e_{max}$ i.e. at the moment of starting.

We can determine the real value of the arm of rolling resistance torque during starting from the equilibrium condition:

$$R\cdot e=M_n \tag{4}$$

We put value of $e$, determined from the above, into the proper differencial equation of the mathematic model.
Fulfilment of the proper condition of the system (3) determines the selection of the adequate model.

### 3.3. Slip

At the moment when the value of the driving torque exceeds the value of the torque resulting from the adhesion of the wheels to substrate, both the slip and the change of the mathematical model will occur. That change is conditioned by the dependence:

state without slip 1. $M_n - R\cdot e \le R\cdot u$

slip 2. $M_n - R\cdot e > R\cdot u$ (5)

where: e - real value of the arm of rolling resistance torque,
u - adhesion coefficient of the wheel to substrate assuming the model of Coulomb friction.

Filfilment of one condition out of (5) causes transition to the proper mathematical model.

Checking of the conditions takes place in every step of integration.

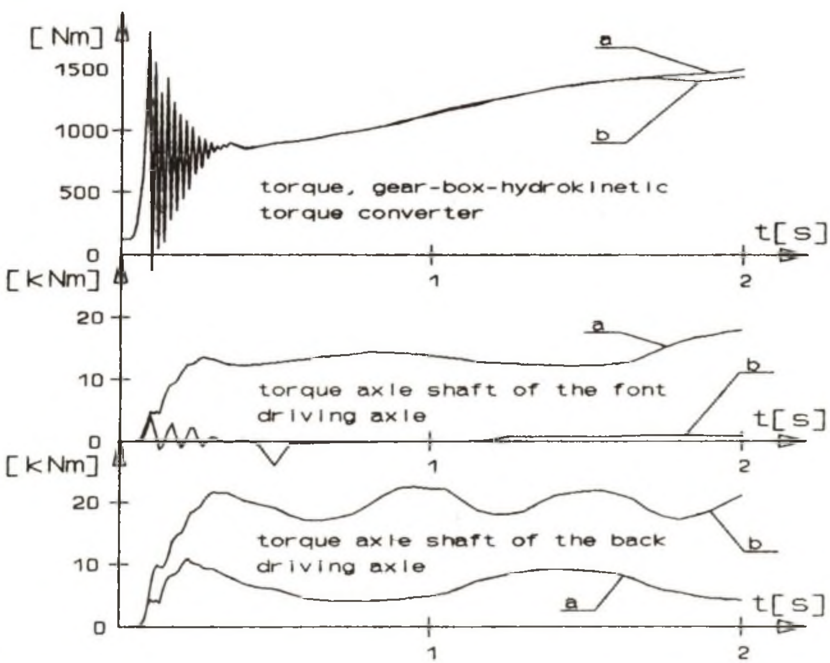


Fig.5. Analitical torque moment courses, during overload
a - dynamic loads calculated durin the start with full sliding in the hydrokinetic torque converter,
b - as above, with carrying up front driving axle

## 4. Conclusion

Obtained results of the described method - taken by way of example the curve in Fig.5. - verified during measurements on the real object, are satisfactory.

Developed programs ODUN1, DOUN2, ODLUT FOR also enable to study the other dynamic phenomena in the power transmission system of wheeled loaders, such as: overloads in the cycles simulating overloads, effect of clearances, change of travelling direction without complete stoppage of the machine and the like.

The programs, enabling study the other phenomena, such as: snaking, circulate power, porpoising, etc, are in the course of their development.

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