Biblid: 1450-5029, (2025) 29; 1; p 6 - 8
UDK: 681.3
DOI: 10.5937/jpea29-56838
Expert Paper

DYNAMIC ANALYSIS OF CUTTING FORCE IN CAM MECHANISM USING BOND GRAPH MODELING

DINAMIČKA ANALIZA SILE REZANJA BREGASTOG MEHANIZMA PRIMENOM BOND GRAF MODELOVANJA

DraganaTRAJKOVIĆ[1], Slobodan STEFANOVIĆ[1], Milan STEFANOVIĆ[2],
[1] Akademija tehničkih i strukovnih studija, Vranje, Filipa Filipovića 20
[2]Univerzitet u Nišu, Mašinski fakultet , Niš, Aleksandra Medvedeva 14
∗ Correspondence: dragana.trajkovic@akademijanis.edu.rs

ABSTRACT

This paper presents a method for determining the gain of the drive motor (electric motor) of the cam mechanism in a universal lathe for metal machining by chip removal. By calculating the values of the variable mathematical parameters of the model as a function of time, the dynamic behavior of this cam mechanism model is obtained. The cam mechanism is schematically shown physically, abstractly, and with bond graphs and includes both automatic and programmed movement of the lathe through a rigid program carrier.
Keywords: *Cam mechanism, bond graph, cam mechanism diagram.*

REZIME

U radu je prikazan način određivanja pojačanja pogonskog motora (elektromotora) kulisnog mehanizma univerzalnog struga za obradu metala skidanjem strugotine. Proračunom vrednosti promenljivih matematičkih pametara modela u funkciji vremena dobija se dinamičko ponašanje ovog modela bregastog mehanizma. Bregasti mehanizam je šematski prikazan fizički, apstraktno,i preko bond grafova i preko čvrstog nosioca programa i obuhvataju automatsko i programirano kretanje struga preko čvrstog nosioca programa.
Ključne reči: *Bregasti mehanizam, bond graf, šema bregastog mehanizma.*

INTRODUCTION

The mathematical model changes the real values with approximate values, which is solved with numerical integration. Special behavior of the model can be caused by the discontinuity in the process of numerical analysis and graphically obtained results. The mathematical model consists of a simulation field of discrete and combination events that can be combined into models. The simulations can be mined with direct graph schemes. The cam mechanism, shown in this paper includes automatic and programmed movement of the lathe via a solid program carrier. This mechanism of transmission belongs to an open control system. This paper shows the bond graph modeling for program simulation getting the results for better programming calculation of the machine mechanism. The out results depend on time or numerical data.

PHYSICAL SYSTEM MODELING

The modeling process consists of obtaining graphs or mathematical models. The input functions are checked with corrections. Every change in the shape of the cam cause changing of processing shape. The transmission system of information belongs to coping machines. The picture shown in *fig. 1* has three subsystems: processing system, material flow system, and control system (cam system).

On the same shaft *(1)* there is a cam mechanism *(2)* and a cam plate *(3)*. The rotational movement of the pulley is transmitted with mechanism, due to the axial movement of the workspace *(4),* which is possible in longitudinal processing. The solid cam construction gives the shape of the product. The shown mechanism in *fig. 1* can be translated on an approximate model suitable for bond graph modeling, as shown in *fig. 2*. The mass movement m_1 in the horizontal direction is shown by spring, and force *F* and the carrier of the pulley mechanism is the mass m_2 with the movement of the leg m_3 on the workpiece.

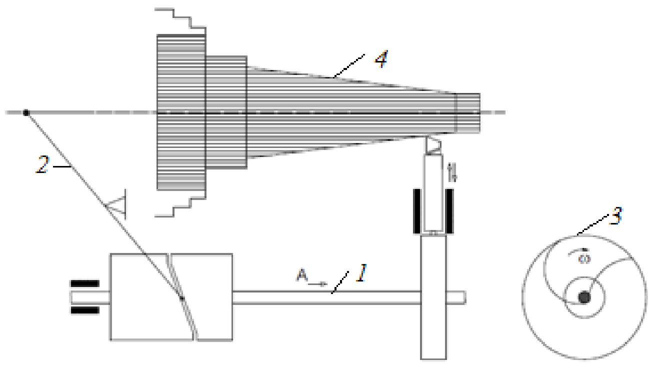

Fig. 1. Principle scheme of the cam mechanism

The following values are used for processing the cone with a cam mechanism:

- Rough machining of a cause with a diameter of Ø70 to a diameter Ø86 in a length of 8 mm under angle of *45°* and tool geometry of $\kappa=45°$, $\kappa_1=45°$, $r=0.8$ mm, $\alpha=5°$, $\gamma= - 6°$ and $\lambda= - 6°$,
- Step value is $s=0.2$ *mm/o*,
- Tool stability is $T=90min$,
- Correction factor for cutting speed is $k_T = 0.73$**.**

The knee speed is given with relationship: $\nu = \nu_n \cdot k_T = 105 \cdot 0.73 = 76.65mm$

$$n = \frac{1000\nu}{\pi D} = \frac{1000 \cdot 76.65}{\pi \cdot 86} = 283.7o / min$$

The specific power is p $=0.064kW/cm^3/min$. The power required for the shown operation amounts is:

$$P = \frac{a \cdot s \cdot v}{2} \cdot p = \frac{\pi \cdot D \cdot a \cdot s \cdot n}{2000} \cdot p$$
$$= \frac{\pi \cdot 86 \cdot 2.5 \cdot 0.2 \cdot 250}{2000} \cdot 0.064 = 1.08kW$$
$$< P_M = 7.5kW$$

The main processing time for this procedure is:

$$t_g = i \cdot \frac{L}{n \cdot s} = i \cdot \frac{l + l_1 + l_2}{n \cdot s} = 3 \cdot \frac{11.28 + 2}{250 \cdot 0.2} = 0.8 \min$$

Cutting force is given with the equation:

$$F_R = \frac{F_1}{\cos(\rho - \gamma)} = 14{,}22 \text{ kN.}$$

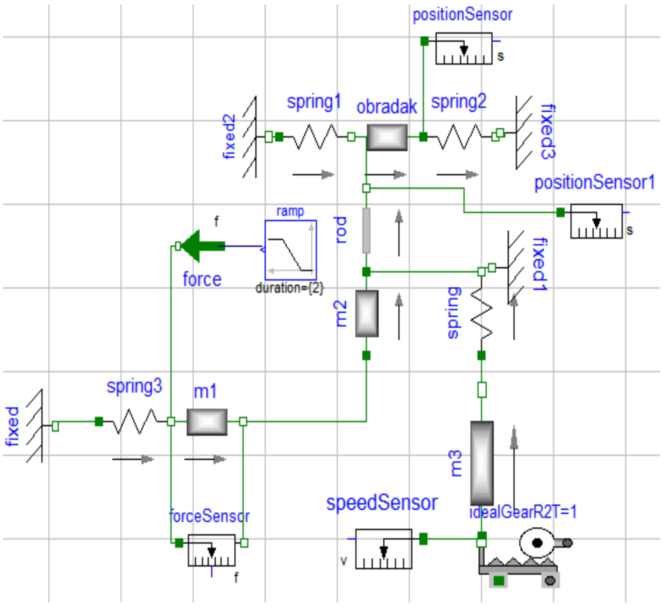

Fig. 2. The Bond graph approximate model of cam mechanism

This system has two freedoms of geometric movement. Input values on mass m_1 are the force F and spring; input values for all systems are force F and angular value ω of the motor. The goal is to keep the change of the displacement Δx_2 to continues value in case of a stationary state (as input vector), it is necessary to determine booster. Gain factor k_{ot} can regulate the displacement Δx_2 keep constant with change of the input of the force F and angular velocityω. On the basis of the law on conservation of (kinetic) energy during the rotational motion of the material system, it is obtained:

$$\frac{dE_k}{dt} = \frac{1}{2}\frac{d(J\omega^2)}{dt} = Pa - Pp \qquad (1)$$

The change in the moment of inertia of the motor is given by the equation:

$$\frac{d(J\omega^2)}{dt} = \omega(M_a - M_{ot}) \qquad (2)$$

The relative deviations of certain physical quantities are given by the following relations:

$$\omega(t) = \frac{\omega(t) - \omega_z(t)}{\omega_z} \qquad (3)$$

The relative moment changed is:

$$\Delta M(t) = \frac{M_a - M_{aN}}{M_{aN}} \qquad (4)$$

The gain coefficient is:

$$k_{ot} = \frac{M_{ot}}{M_{aN}} \qquad (5)$$

Cutting time is:

$$T = \frac{J\omega_z}{M_{aN}} \qquad (6)$$

Where is:
P_a - active driving power of the machine
P_p - passive of resistance power
M_o - active moment
M_{ot} - resistance moment
ω_z - desired angular velocity
M_{ot} - resisting moment
M_{an} - nominal active moment
$\alpha = f(\Delta x_3)$ – motor gain factor in function of displacement x_3.

Bond graph model of cam mechanism

The bond graph model of the cam mechanism is shown in figure 3. Based on the bond graph scheme, it is obtained that the speed of the workpiece is equal to the sum of the movement speed of the cam mechanism and the moving mechanism of the knife:

$$v_3 = \alpha(v_1 + v_2) \qquad (7)$$

$$\frac{dv_3}{dt} = \alpha\left(\frac{dv_1}{dt} + r\alpha\frac{d\omega}{dt}\right) \qquad (8)$$

$$\frac{dv_3}{dt} = \alpha\left(\frac{dv_1}{dt} + r\omega\frac{dx_1}{dt}\frac{d\alpha}{dx_1}\right)/\text{m}_3 \qquad (9)$$

$$\Delta x_3 = \frac{1}{s}\alpha(v_1 + r\dot{\omega}) \qquad (10)$$

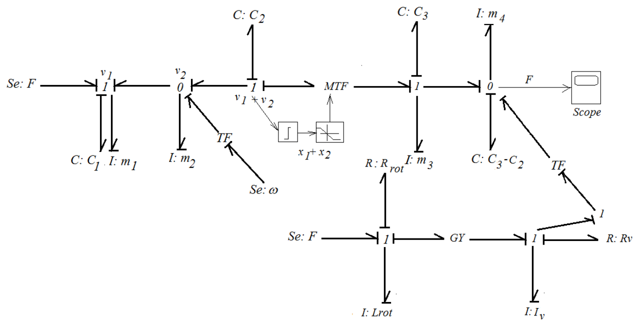

Fig. 3. Bond graph scheme of the cam mechanism

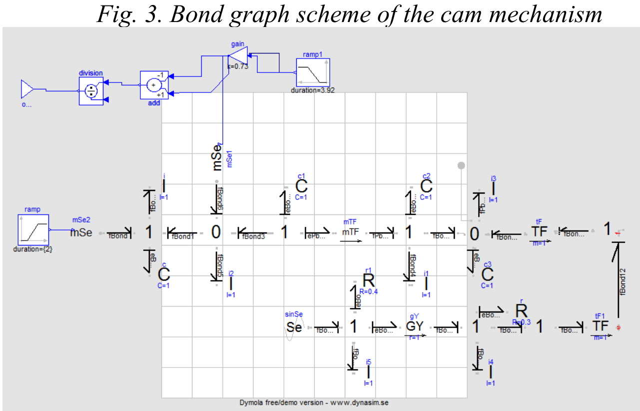

Fig. 4. Application of Modelica library for bond graph modeling and simulation results

CONCLUSION

Bond graph methodology was used to parameters modeling and describes the dynamic behavior of the system. The Bond graph scheme is used for modeling and analyzing dynamic systems that involve energy flows between different components. In the context of the cam mechanism, the bond graph allows:

- *Graphic representation of energy flows* - shows how energy is transferred and transformed between components.
- *Mathematics systems modeling* – enable derivation of differential equations and describe the dynamic behavior of the dynamic system, mechanism.
- *Simulations and performance analysis* – enable the estimation of parameters such as forces, moment, and acceleration. In this case, the simulations of cam production include the following key aspects:

1. *Kinematics and Dynamics of the cam mechanism* - Determining the movement of a cam mechanism, including how the components move in relation to the bevel (cone).
2. *Forces and moments* - Calculation of forces and moments transmitted through the cam mechanism during machining, taking into account the specific forces acting on the tool and material.
3. *Performance simulation* – Using the bond graph model to analyze speeds, accelerations, and loads during cone processing, which helps optimize parameters for more efficient operation of the mechanism.

The simulation would include the dynamics of machining, which may include the optimization of tool movement in relation to the machined surface of the cone in order to achieve the desired machining quality.

REFERENCES

Journal of the Franklin Institut, Pergamon Press, “Modeling Complex Vehicle Systems Using Bond Graphs“, Vol 319, No. ½, pp. 67-81, January/ February, Great Britain, 1985.

Miodrag T. Manić, Dušan N. Spasić, “Numerically control machines“, Faculty of Mechanical Engineering-High school, Niš 1998.

S. Stefanović, “Authorized lectures on Mechanical Elements", Academy of Technical-Educational Vocational Studies, Vranje, 2023.

Staniša Perić, Dragana Trajković, Dragan Antić, Vlastimir Nikolić, Saša S. Nikolić, Miroslav Milovanović, “Fuzzy-PI Control of Water Pumps Modelled by Hybrid Bond Graphs”, FACTA UNIVERSITATIS Series: Automatic Control and Robotics, vol. 14, no. 1, (2015), pp. 29-42. Print ISSN: 1820-6417, Publisher: University of Niš. June 2015.

Dragana M. Trajković, Branislav Dimitrijević, “Bond Graph Bicausality Modeling The Hydraulic System“, KNOWLEDGE – International Journal Vol.54.3, 2022. Greece

D. Trajković, V. Nikolić, D. Antić, B. Danković, "Analyzing, Modeling and Simulation of the Cascade Connected Transporters in Tyre Industry Using Signal and Bond Graphs"- Machine Dynamics Problems (Research), Publisher: Warsaw University of Technology, ISSN 2080-9948, Vol 29, No 3, 2005., pp.2-15

D. Trajković, V. Nikolić, D. Antić, S. Nikolić, S. Perić, “Application of the Hybrid Bond Graphs and Orthogonal Rational Filters in Sag Voltage Effect Reduction”, Electronics and Electrical Engineering, vol. 19, no. 6, (2013), pp. 25-30. Print ISSN: 1392-1215, (Doi No: http://dx.doi.org/10.5755/j01.eee.19.6.1746) Publisher: Kaunas University of Technology. June 2013. IF: 0.445.

Received: 17. 02. 2025.   Accepted: 20. 03. 2025.