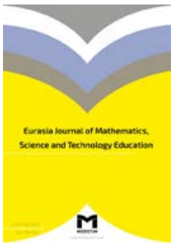

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Dynamic Simulation of Mechanism in Theory Mechanics Teaching

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ABSTRACT
A new teaching method is put forward in theory mechanics teaching practice. This new teaching method advocate the application of numerical simulation in theory mechanics teaching practice foster the ability of grasping the whole process of a kinematic period of the mechanism from a macroscopic view. By using dynamic simulation technology of mechanism, the mechanical engineer can realize the process of mechanism motion animation simulation and decrease the difficulty of students understanding of the mechanism motion process. Dynamic simulation technology can also provide important reference for the following mechanism design and set up the theoretical study and engineering practice.

Keywords: numerical simulation, kinematics of mechanism, theory mechanics teaching, synthetic motion of points

INTRODUCTION

For a student major in mechanical engineering, the kinematics knowledge in theory mechanics are mainly used to analyze the driven member and operating member of a mechanism from the driving member. In the actual teaching process, teachers and students often committed to solve the transient kinematic problem of a mechanism, and lose sight of the study of mechanism motion period usually (Gurel, et al., 2015). However, a mechanical engineer needs to grasp the whole process of a kinematic period of the mechanism from a macroscopic view. In this way, knowledge that students learned and used to is disconnected. The study found that case teaching method by dynamic simulation technology is an effective means to solve this kind of teaching problem (Chou, 2001; Edelson, 1996; Irby, 1994; Majeed, 2014; Morrow & Epling, 2003; Tan & Zheng, 2014; Thomas & Albert, 2001).

Utilizing dynamic simulation technology of the mechanism to simulate the animation of the mechanism in theory mechanics teaching, students can comprehend the whole kinematical characteristics of the mechanism and calculate any moment kinematic parameters within the scope of one movement cycle more easily. As an example, the following shaping machine transmission mechanism is used to illustrate the dynamic simulation application in the teaching of theory mechanics.

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State of the literature

- Studies on case teaching method by dynamic simulation technology have gained impetus over the last decades. The main aim of these studies is to improve theory mechanics teaching quality by using dynamic simulation technology.
- Utilizing dynamic simulation technology, Students can comprehend the whole kinematical characteristics of the mechanism cycle.

Contribution of this paper to the literature

- The significance of the present study lies in its contribution to the literature with an implementation cases about theory mechanics teaching by dynamic simulation of mechanism method.
- According to the study, this new teaching method can foster the ability of grasping the whole process of a kinematic period.
- The results of this study shows adopting case teaching method can improve the teaching quality of theoretical mechanics.

ANALYTIC COMPUTATION OF TRANSIENT MOTION BASED ON KINEMATIC FORMULA

By using the kinematics formula of the theoretical mechanics' knowledge, kinematics parameters of the mechanism on a certain moment can be calculated easily. As an example, the following shaping machine transmission mechanism demonstrates the process of solving the transient kinetic parameters.

The shaper mechanism motion diagram is shown in **Figure 1**. Crank AB rotates around fixed axis A with angular velocity ω_1, which is the driving member of the whole mechanism and its length is l_1. Guide rod CD rotates around fixed axis C with angular velocity ω_3 and its length is l_3. Connecting rod DE does planar motion and its length is l_4. The operating member FG does lead translational motion reciprocation with a certain lead and its velocity is v_5. The distance between fixed support A and C is l_6. The distance between fixed support C and ram FG is l_7.

The transmitting way of the power from crank AB to ram FG includes the following several process.

As a calculating example, let l_1=0.125m, l_3=0.600m, l_4=0.150m, l_6=0.275m, l_7=0.575m, the crank AB rotate with a constant angle speed, that is ω_1=1rad/m. Fixed axis rotation of the crank AB translates into reciprocating swing of guide rod CD through slider B.

The power transmission route of the shaper mechanism is as follows. The crank AB rotating around a fixed axis drive guide rod CD moves reciprocal pendulum, and drive further the operating member FG does lead translational motion reciprocation through connecting rod ED.

The composition formulae of velocity and acceleration in theoretical mechanics and the base point method in a planar moving body can realize arbitrary planar mechanism kinematics under the transient. The composition formulae of velocity is as follow

$$\overline{v}_a = \overline{v}_e + \overline{v}_r \tag{1}$$

Where $\bar{v}_a$ is the absolute speed, $\bar{v}_e$ is the transport velocity, $\bar{v}_r$ is the relative velocity. This formula reveals that the absolute velocity of moving point in a transient equals to the instantaneous relative velocity in a moving frame of reference vector sum the transport velocity of the moving frame relative to the fixed frame.

Let sliding block B is the moving point, and the moving frame of reference is fixed on guide rod CD, the above mentioned three velocities are as shown **Figure 2**. The absolute speed $\bar{v}_a$ is perpendicular to Crank AB, the transport velocity $\bar{v}_e$ is perpendicular to CD, the relative velocity $\bar{v}_r$ is parallel to guide rod CD and the absolute value of $\bar{v}_a$ is $\omega_1 l_1$. Assume that the distance between sliding block B and fixed bearing C is s_3 and the absolute values of speed $\bar{v}_e$ and $\bar{v}_r$ are

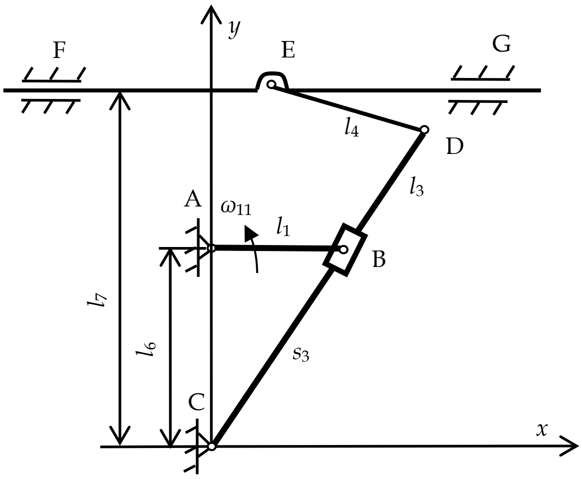

Figure 1. Kinematic sketch of mechanism of the shaping machine

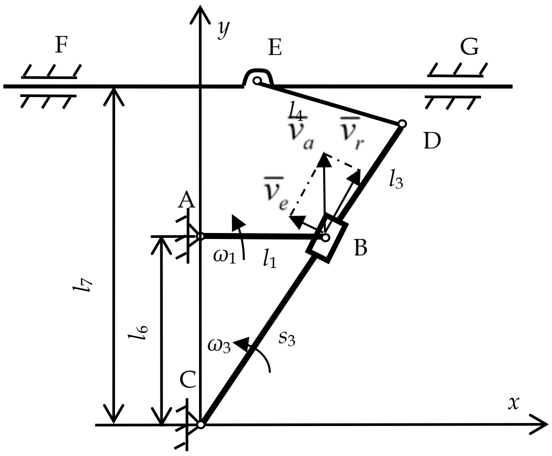

Figure 2. Velocity analysis of guide-bar mechanism

$$\begin{cases} v_a \sin\angle ABC = v_e \\ v_a \cos\angle ABC = v_r \end{cases} \tag{2}$$

It is easy to get the following mathematical relationship from the geometric relationship of **Figure 2**, $\sin\angle ABC = \frac{l_1}{s_3}, \cos\angle ABC = \frac{l_6}{s_3}, l_6 = \sqrt{l_1^2 + l_6^2}$. According to the definition of transport velocity, $v_e = \omega_3 s_3$. Considering the above relationship, $\omega_3 = \frac{l_1^2\omega_1}{l_1^2+l_6^2}, v_r = \frac{\omega_1 l_1 l_6}{\sqrt{l_1^2+l_6^2}}$.

Let the angular speed of guide rod CD is ω_3, the absolute value of linear velocity $\bar{v}_D$ is $\omega_3 l_3$ and its orientation is perpendicular to guide rod CD which is shown as **Figure 3**. Because the motion state of connecting rod ED is a kind of planar motion, it's easy to find the kinematic relationships between point D and point E by setting point D as base point.

$$\overline{v}_E = \overline{v}_D + \overline{v}_{ED} \tag{3}$$

Where, the orientation of $\bar{v}_E$ is horizontal, the orientation of $\bar{v}_{ED}$ is perpendicular to guide rod ED, and the vector composition of these three velocity is shown as **Figure 3**.

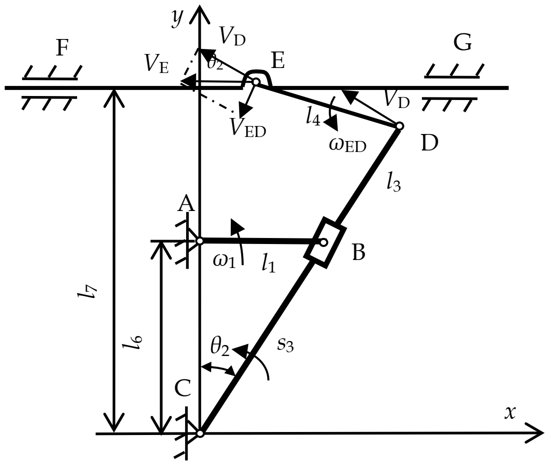

Figure 3. Velocity analysis of connecting bar

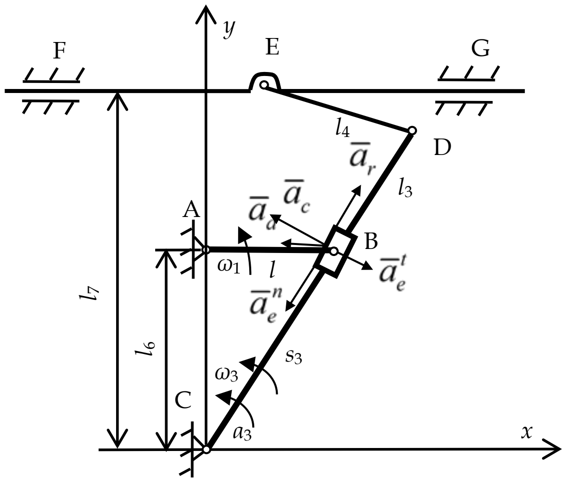

Figure 4. Acceleration analysis of guide-bar mechanism

Calculating the velocity of the operating member FG is v_E=0.2212m/s, and the angular velocity is ω_{ED}=0.2928rad/s according to velocity vector composition shown as **Figure 3**.

Let sliding block B is the moving point, and the moving frame of reference is fixed on guide rod CD, the acceleration orientations are as shown **Figure 4**.

The absolute value of the absolute acceleration $\overline{a}_a$ is $\omega_1^2 l_1$ and its orientation direct along the AB rod. The absolute value of the normal transport acceleration $\overline{a}_e^n$ is $\omega_3^2 s_3$, and its orientation direct along the BC rod. The absolute value of the tangential transport acceleration $\overline{a}_e^t$ is $\alpha_3 s_3$, (α_3 is an unknown), and its orientation is perpendicular the BC rod. The relative acceleration is an unknown parameter, and its orientation direct along the BC rod. The Coriolis acceleration is an unknown, and its orientation is perpendicular the BC rod. According to acceleration vector of point composition formula, these above acceleration vector satisfy the following mathematic relation

$$\overline{a}_a = \overline{a}_e^n + \overline{a}_e^t + \overline{a}_r + \overline{a}_c \tag{4}$$

Two independent algebraic equations can be gotten by projecting the vector equation (4) to x and y axis. It's easy to get $\alpha_3 = \frac{l_1 l_6 (l_6^2 - l_1^2)}{(l_6^2 + l_1^2)^{3/2}}$ by solving the algebraic equations, and its rotation direction is shown as **Figure 4**.

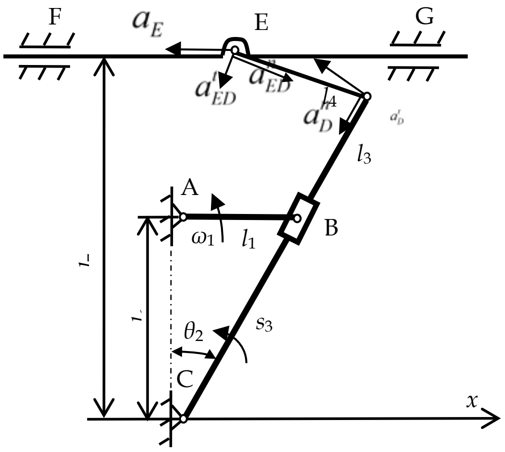

Figure 5. Acceleration analysis of connecting bar

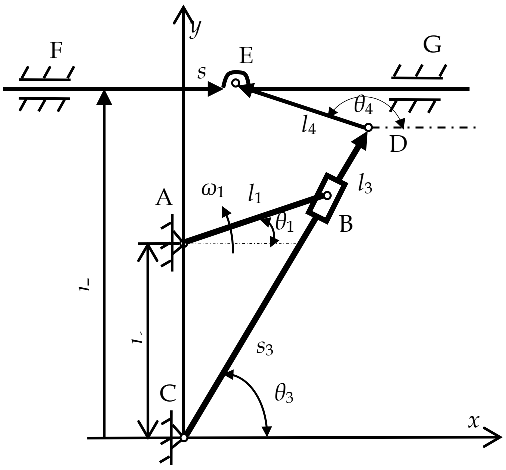

Figure 6. Motion geometry relationship of the shaper mechanism

Set point D as base point, analyze the acceleration vector $\overline{a}_E$ of ram FG by using the method of base point, and the direction of is shown as **Figure 5**.

The orientation of $\overline{a}_D^t$ is perpendicular the CD rod, the orientation of $\overline{a}_D^n$ direct along the CD rod, the orientation of $\overline{a}_{ED}^t$ is perpendicular the ED rod, the orientation of $\overline{a}_{ED}^n$ direct along the DE rod, $\overline{a}_E$ is parallel ram FG. These above acceleration vector satisfy the following formula

$$a_E = a_D^t + a_D^n + a_{ED}^t + a_{ED}^n \tag{5}$$

where, the absolute value of acceleration $\overline{a}_E$ is an unknown, normal acceleration, $a_D^n = \omega_3^2 l_2$ the tangential acceleration $a_D^n = \alpha_3 l_3$, the normal acceleration $a_D^n = \omega_3^2 l_2$, the tangential acceleration $a_{ED}^n = \alpha_{ED} l_4$ ($\alpha_{DE}$is an unknown), the normal acceleration $a_{ED}^n = \omega_{ED}^2 l_4$. Two independent algebraic equations can be gotten by projecting the vector equation (5) to x and y axis. It's easy to get the solutions of the algebraic equations, that is a_E=0.2597m/s^2.

NUMERICAL SIMULATION OF THE SHAPER MECHANISM

It's easy to calculate the kinematical parameters of the mechanism on a transient moment by using the above theories. In order to get the kinematics of the shaper mechanism in a working period, the mechanical engineer can divide take an work period into finitely many transient motion, and then repeat the above formula parsing process to obtain every kinematical parameters of the mechanism. Finally, the kinematics rule of the shaper mechanism in a working period can be gotten by synthesizing these kinematical parameters in a cycle.

Suppose crank AB is definitely on level ground at the internal stage, and **Figure 6** shows the motion geometry relationship of the shaper mechanism at some point. The Angle between crank AB and horizontal line is called θ_1, the Angle between guide rod CD and horizontal line is called θ_3, the Angle between linkage ED and horizontal line is called θ_4.

According to the vector composition relation

$$\begin{cases} \overline{l_6} + \overline{l_1} = \overline{s_3} \\ \overline{l_7} + \overline{s_E} = \overline{l_3} + \overline{l_4} \end{cases} \tag{6}$$

Two independent algebraic equations can be gotten by projecting the vector equation (6) to x and y axis

$$\begin{cases} l_1 \cos\theta_1 = s_3 \cos\theta_3 \\ l_6 + l_1 \sin\theta_1 = s_3 \sin\theta_3 \\ l_3 \cos\theta_3 + l_4 \cos\theta_4 = s_E \\ l_3 \sin\theta_3 + l_4 \sin\theta_4 = l_7 \end{cases} \tag{7}$$

The velocity relation of every component in mechanism can be gotten by calculating the derivative of the equation (7)

Where, ω_3 denotes the angular speed of guide rod CD, ω_4 denotes the angular speed of linkage CD.

The acceleration relation of every component in mechanism can be gotten by calculating the derivative of the equation (8)

$$\begin{bmatrix} \sin\theta_3 & s_3\cos\theta_3 & 0 & 0 \\ -\cos\theta_3 & s_3\sin\theta_3 & 0 & 0 \\ 0 & l_3\sin\theta_3 & l_4\sin\theta_4 & 1 \\ 0 & l_3\cos\theta_3 & l_4\cos\theta_4 & 0 \end{bmatrix} \begin{bmatrix} v_r \\ \omega_3 \\ \omega_4 \\ v_E \end{bmatrix} = \omega_1 \begin{bmatrix} l_1\cos\theta_1 \\ l_1\sin\theta_1 \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} \sin\theta_3 & s_3\cos\theta_3 & 0 & 0 \\ -\cos\theta_3 & s_3\sin\theta_3 & 0 & 0 \\ 0 & l_3\sin\theta_3 & l_4\sin\theta_4 & 1 \\ 0 & l_3\cos\theta_3 & l_4\cos\theta_4 & 0 \end{bmatrix} \begin{bmatrix} a_r \\ \alpha_3 \\ \alpha_4 \\ a_E \end{bmatrix} = - \begin{bmatrix} \omega_3\cos\theta_3 & v_r\cos\theta_3 - s_3\omega_3\sin\theta_3 & 0 & 0 \\ -\omega_3\sin\theta_3 & -v_r\sin\theta_3 - s_3\omega_3\cos\theta_3 & 0 & 0 \\ 0 & l_3\omega_3\cos\theta_3 & l_4\omega_4\sin\theta_4 & 0 \\ 0 & -l_3\omega_3\sin\theta_3 & -l_4\omega_4\sin\theta_4 & 0 \end{bmatrix} \begin{bmatrix} v_r \\ \omega_3 \\ \omega_4 \\ v_E \end{bmatrix} + \omega_1 \begin{bmatrix} -l_1\omega_1\cos\theta_1 \\ -l_1\omega_1\sin\theta_1 \\ 0 \\ 0 \end{bmatrix} \tag{9}$$

where, α3 denotes the angular acceleration of guide rod CD, α4 denotes the angular acceleration of connecting rod CD.

It's easy to get the simulation curves of all kind of kinematics parameters of the shaper mechanism in a working period by numerical method of ODE45, which are shown from **Figure 7** to **Figure 10**.

A mechanical engineer can observe the complete picture of the mechanism kinematics conveniently. **Figure 8** shows a clear quick-return characteristic, that is to say the velocity of working stroke is very slow, and the velocity of return stroke is very high. The quick-return characteristics of the mechanism is good for the working efficiency and processing quality. **Figure 9** is ram acceleration curve with time in a working process. Animation of the shaper mechanism in a in a working period is shown as **Figure 10**.

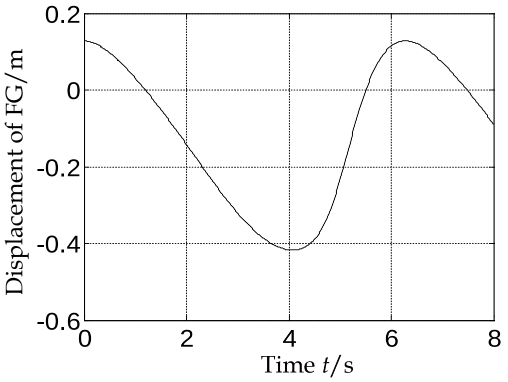

Figure 7. Ram displacement curve with time

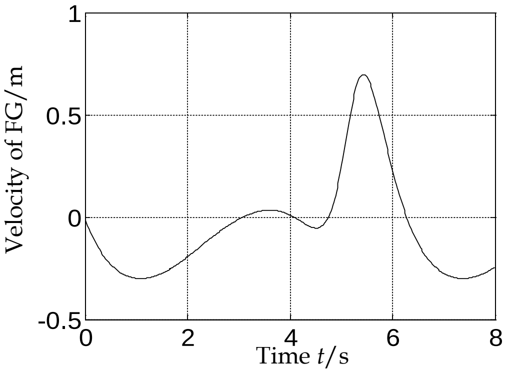

Figure 8. Ram velocity curve with time

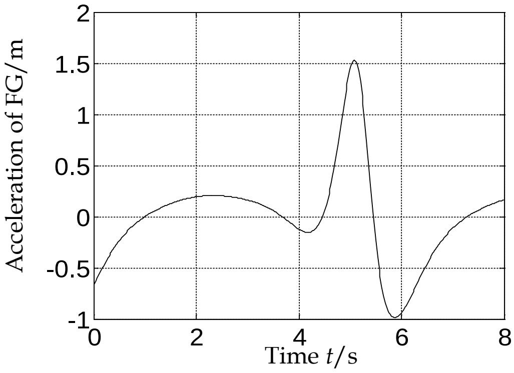

Figure 9. Ram acceleration curve with time

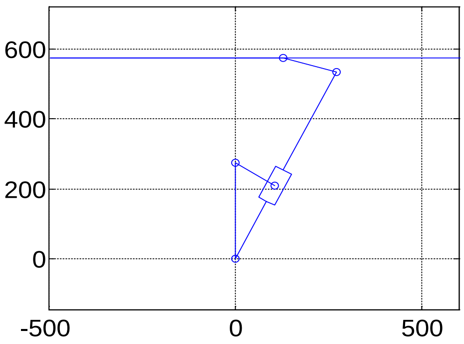

Figure 10. Animations of the mechanism

DISCUSSION CONCLUSION AND RECOMMENDATION

From the **Figure 7**, students can access ram displacement information in a movement cycle and get the maximum machining stroke of machine. **Figure 8** show ram velocity curve with time, and students can get quick-return characteristics which the operating stroke velocity is very slow, but the noncutting stroke velocity is very quick. **Figure 9** show ram acceleration curve with time, and students can get the maximum dynamic load in a movement cycle of the machine. From the **Figure 10**, students can students can comprehend the whole kinematical characteristics of the mechanism and calculate any moment kinematic parameters in a movement cycle of the machine.

In this paper, a new teaching method is put forward in theory mechanics teaching practice. This new teaching method advocate the application of numerical simulation in theory mechanics teaching practice foster the ability of grasping the whole process of a kinematic period of the mechanism from a macroscopic view.

By using dynamic simulation technology of mechanism, the mechanical engineer can realize the process of mechanism motion animation simulation and decrease the difficulty of students understanding of the mechanism motion process. It’s easy to calculate the kinematical parameters of the mechanism on every transient moment within the scope of one movement cycle and help students grasp mechanism kinematics. Dynamic simulation technology can also provide important reference for the following mechanism design and set up the theoretical study and engineering practice.

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