MOTION ANALYSIS OF WHITWORTH QUICK RETURN MECHANISM

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ABSTRACT

Mechanisms are widely used in engineering as components of different types of machines and devices. In this paper, careful consideration is given to the studying and motion analysis of Whitworth quick return mechanism, which represents a modification of slider-crank mechanism. This mechanism has many applications, but mostly is used in machine tools and hydraulic machines (pumps). From an engineering standpoint, the quick return mechanism impacted the technology of the Industrial Revolution by minimizing the duration of a full revolution, thus reducing total machining time and cost. In this paper, the structure of a quick-return mechanism is explained, as well as motion analysis which includes determination of velocity and acceleration by using SolidWorks feautures. Also, the input parameters used for this method are optimized to imitate the mechanism motion in real conditions.

Keywords: Whitworth, mechanism, motion, analysis, SolidWorks, optimization

1. STRUCTURE OF WHITWORTH QUICK RETURN MECHANISM

The Whitworth quick return mechanism is a mechanical device that converts rotary motion into reciprocating motion. It was invented by Sir Joseph Whitworth, a British engineer, in the mid-19th century. The mechanism consists of a rotating crankshaft that drives a connecting rod, which in turn drives a slider. The slider moves back and forth in a straight line, perpendicular to the direction of the crankshaft's rotation. The distinguishing feature of the Whitworth quick return mechanism is that the forward stroke of the slider is slower than return stroke. This is achieved by arranging the connecting rod and slider in such a way that they are closer together during the forward stroke than during the return stroke. The Whitworth quick return mechanism is commonly used in shaping machines, where it provides the reciprocating motion needed to move the cutting tool back and forth across the workpiece. It is also used in other mechanical devices where a quick return motion is required, such as in pneumatic and hydraulic pumps, [5][6]. Whitworth quick return mechanism consists of the following components, Figure 1:

1. Crank (2): The crank rotates with uniform angular velocity. It gets power from a pinion wheel or motor (1).
2. Slotted bar (4) and slider (3): It is a bar with a slot for guiding a slider into it. The slider is connected to the end of the crank. The slotted bar is pivoted at a fixed origin. Its other end is connected to the connecting rod.
3. Connecting rod (5): The aim of connecting rod is to convert the rotary motion of the end of the slotted bar into reciprocating motion.
4. Ram (6): The ram reciprocates in the horizontal direction. The shaper or slotting tool is mounted onto the ram.

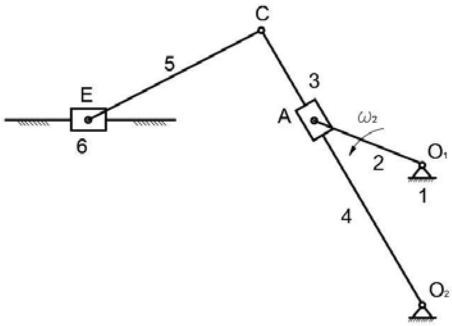

Figure 1. Schematic view of Whitworth quick return mechanism [2]

2. METHODS OF KINEMATIC ANALYSIS

There are several methods for kinematic analysis of the Whitworth quick return mechanism, including:

a) Graphical method: In this method, the mechanism is drawn in its actual size and shape, and the motion of its various components is analyzed using graphical techniques, such as velocity and acceleration diagrams.
b) Analytical method: This method involves the use of mathematical equations and formulas to determine the motion and velocity of the mechanism. The equations are derived from the geometry of the mechanism and the principles of kinematics, [3].
c) Computer-aided method: This method involves using specialized software to create a digital model of the mechanism and simulate its motion. The software can generate data on the position, velocity, and acceleration of the various components of the mechanism.
d) Experimental method: This method involves physically building the mechanism and measuring its motion using various sensors, such as position encoders and accelerometers.

Each method has advantages and limitations, and the choice of method depends on factors such as the complexity of the mechanism, the accuracy required, and the available resources, [4].

3. MOTION ANALYSIS OF WHITWORTH MECHANISM IN SOLIDWORKS

SolidWorks is a 3D computer-aided design (CAD) software program developed by Dassault Systèmes. It is widely used in industries such as aerospace, automotive, architecture, and consumer goods for creating 3D models and 2D drawings of mechanical parts, assemblies, and structures. SolidWorks provides a wide range of tools for creating complex geometries, analyzing the designs for their functionality and manufacturability, and generating production-ready drawings and documentation.

3.1. Model preparation for Motion Analysis in SolidWorks

Model preparation for motion analysis involves setting up the model geometry and constraints to accurately simulate the motion of the mechanism being analysed. Proper model preparation is essential to obtain reliable and meaningful results from the motion analysis.

The following input parameters [1] were used to create the Whitworth mechanism in SolidWorks, Figure 2:

- Crank length r = 480mm,
- Distance a = 240mm,
- Connecting rod length L = 550mm,
- Slotted bar end length R = 170mm,
- Angular velocity of driver $\omega_1 = 21.25s^{-1}$.

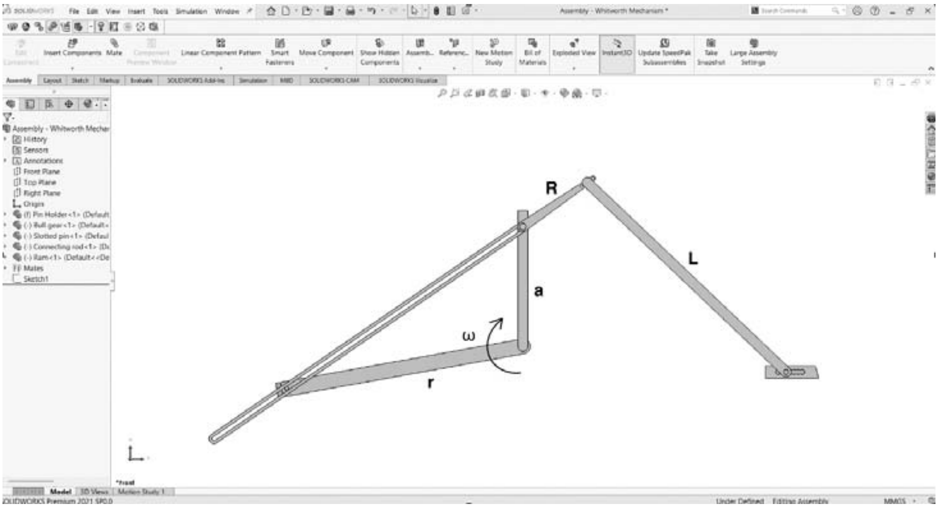

Figure 2. Model of Whitworth quick return mechanism in SolidWorks

After creating each part of the assembly according to the previously defined dimensions, it was necessary to combine created parts into an assembly using appropriate relations/mates. Relations between the assembly parts, fixed supports, the type of motion of individual members of the assembly and the driving member of the assembly/mechanism were defined. It is important to emphasize that material of the mechanism is not defined for the purpose of kinematic analysis of Whitworth quick return mechanism in this case.

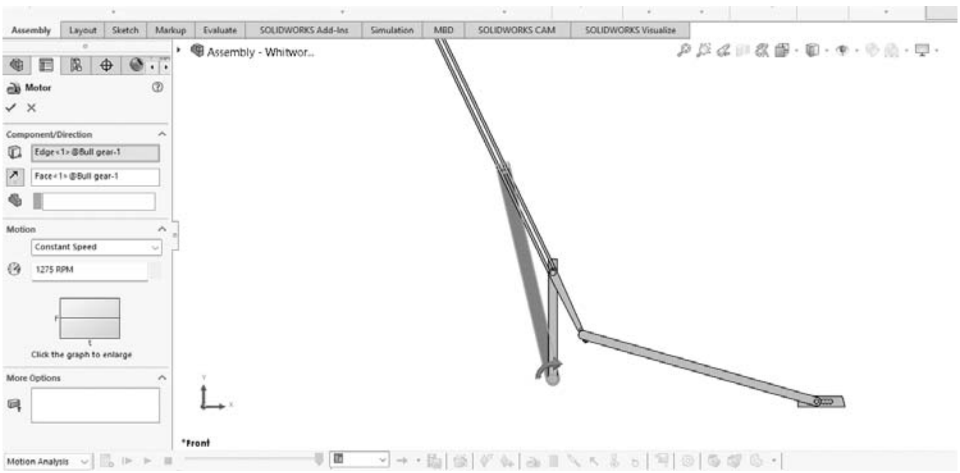

Figure 3. Preparing mechanism parameters for Motion Analysis

Once these parameters were defined, it was necessary to open the "Motion Study" tab and select "Motion Analysis" in the lower left corner, Figure 3. In the next step, it was necessary to define the speed of the driving member and the type of motion.
For the motion of the driving member in this case, a constant angular velocity was selected, and the adopted value was 1275 RPM or 21.25 s^{-1},which was adopted from previous analysis done using analytical and graphical methods of kinematic analysis, [1].

After defining the angular velocity of the driving member, it was necessary to define the time interval in which the motion of the mechanism was going to be analysed. For this particular case, a time interval of 9 seconds was adopted. Also, after all input parameters were defined, it was necessary to select icon „calculate“ in order to calculate the motion study and prepare the mechanism for result analysis, Figure 4.

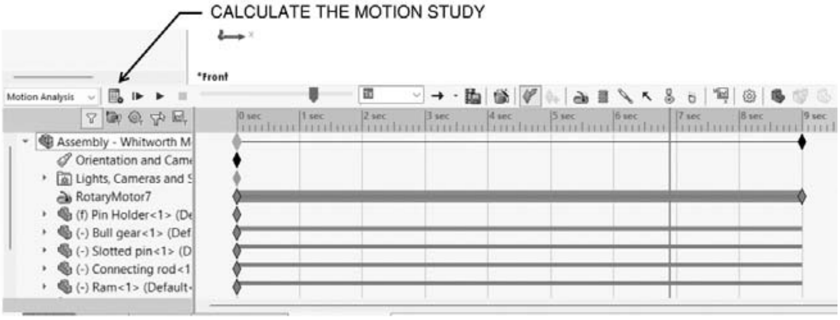

Figure 4. Icon "calculate" necessary for calculation of Motion Study

The results of the motion analysis in SolidWorks were obtained by selecting icon „Results and Plot“ and defining the following:

1. What category of physical quantities was to be analysed and plotted (Displacement/Velocity/Acceleration, Forces, Momentum/Energy/Power, etc.)
2. For which part of the assembly/mechanism results needed to be analysed and plotted.

For motion analysis of Whitworth quick return mechanism, category „Displacement/Velocity/Acceleration“ was selected. To be precise, linear velocity and linear acceleration were physical quantities of the interest for the analysis, Figure 5. Also, the ram, on which the shaper or slotting tool is mounted, was the part of the mechanism whose velocity and acceleration needed to be analysed.

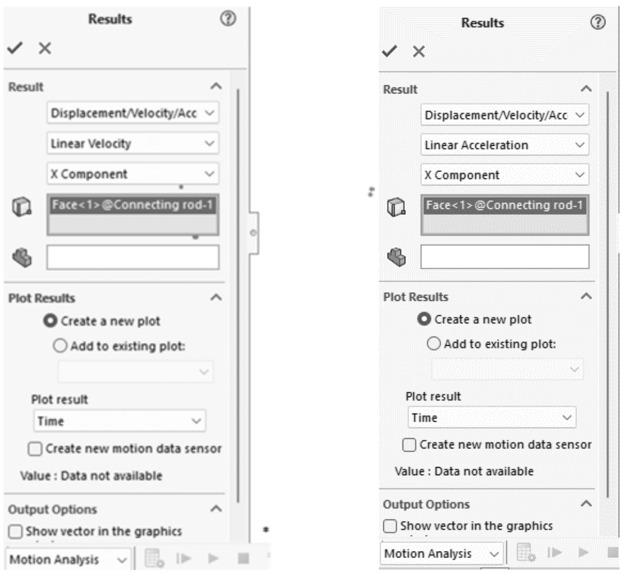

Figure 5. Choosing physical quantities and parts for Motion Analysis

3.2. Results of the Motion Analysis

After defining all the input parameters of the mechanism and physical quantities that needed to be calculated, plot results were obtained and ready to be analyzed. Figure 6 shows plot results for velocity and acceleration of the ram as a function of time.

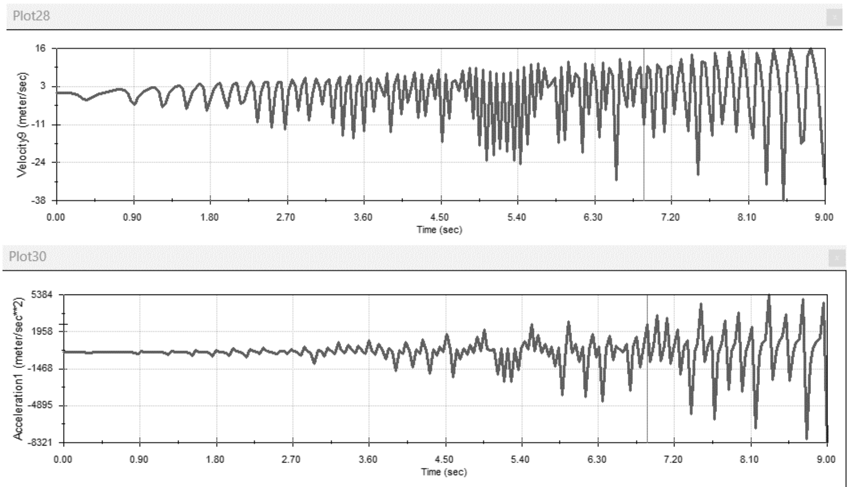

Figure 6. Plot results for velocity and acceleration of the ram as a function of time

By analyzing the results, it can be concluded that using input parameters defined in the paper would lead the Whitworth mechanism to a collapsed state. It can be observed that due to excessive angular velocity of the driving member, the mechanism uncontrollably increases the velocity and acceleration of the slider, which in real conditions could lead to machine failure or, in the worst case, injury to workers in the immediate vicinity. For this reason, it is necessary to optimize the input parameters to enable the mechanism to be used in real conditions. This involves adjusting the input velocity of the driving member or changing the dimensions of individual mechanism members.

3.3. Optimization of input parameters

Dimensions of the Whitworth quick return mechanism remained the same for optimization purpose. However, angular velocity of the driving member (crank) was reduced to $\omega_1 = 0.5s^{-1}$. Preparation for motion analysis was done following the same steps previously described. After defining all the input parameters of the optimized mechanism and physical quantities that needed to be calculated, plot results were obtained and ready to be analyzed. Figure 7 shows plot results for velocity and acceleration of the ram as a function of time. By analyzing the results, it can be concluded that using optimized parameters Whitworth quick return mechanism can function in real conditions. Plot results show slower return stroke of the ram and faster return stroke, which is the main characteristics of Whitworth quick return mechanism. It can be concluded that by reducing the angular velocity of the driving member, the functionality and safe operation of the mechanism were achieved, which was the purpose of the motion analysis.

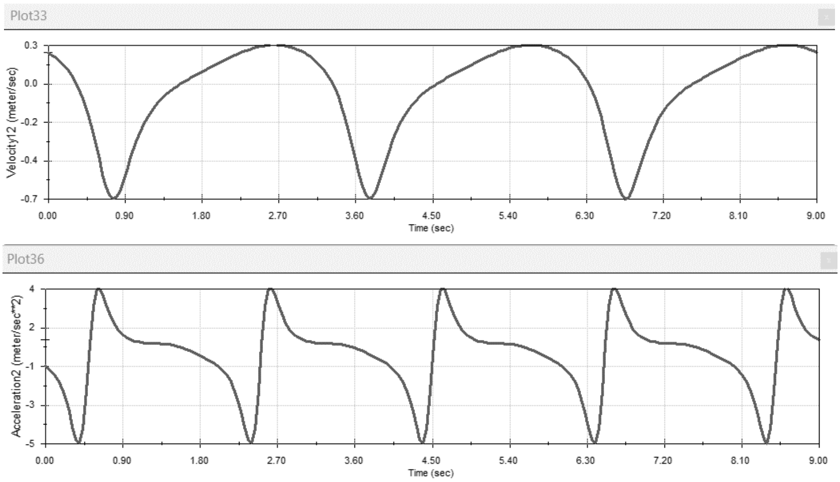

Figure 7. Optimized plot results for velocity and acceleration of the ram as a function of time

4. CONCLUSION

SolidWorks allows engineers and designers to visualize and optimize their designs before they are manufactured. On the example of Whitworth quick return mechanism, it was shown how sometimes standard methods of kinematic analysis such as analytical and graphical methods, are not precise enough for mechanism to be manufactured and operate in real conditions.

From a financial and safety perspective, the assessment and optimization of mechanisms, machines, tools, etc., using SolidWorks or other 3D software can reduce manufacturing costs, repair costs, and prevent machine failures due to insufficiently defined input parameters, dimensions, etc.

However, in a realistic analysis of the working cycle of a mechanism, a combination of methods is typically used to obtain more accurate results. When dealing with more complex mechanisms, greater discrepancies between the results of individual methods are possible. Therefore, it should be emphasized that the computer-aided method is significantly faster and more precise, but the graphical and analytical methods are necessary to fully understand the functioning of the mechanism and how the computer arrived at the corresponding processing results.

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