Kinematic analysis of one degree of freedom mechanisms using the SolidWorks and the MATLAB

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Abstract. The following article intends to present the kinematic analysis of three different mechanisms with one degree of freedom, being one four-bar mechanism, one quick return mechanism, and one slider-crank mechanism using different methods, first the Solidworks motion study tool, and afterwards codes developed in the MATLAB. To determine the dimensions of the elements were utilized a shaping machine for the quick-return mechanism, and the LS3 engine for the slider-crank mechanism. Graphics and maximum values of displacement, velocity, and acceleration for specific frequencies of rotation of the crank were shown, and the results were validated by comparison. Furthermore, some kinematic details of the mechanisms were analyzed, including the ratio between the time of advance and return of the quick-return mechanism. The same results - extreme values and graphics - were found by both methods, which demonstrates that they were correct.

Keywords: SolidWorks, MATLAB, Quick-return mechanism, Slider-crank mechanism, Four-bar mechanism.

1 Introduction

According to Norton [1], a mechanism is a device that transforms any movement in other desirable. Meriam & Kraige [2], state that kinematics of rigid bodies studies the relationships between the rotation and translation movements of bodies, without considering the forces and moments associated with these movements. The kinematic analysis is fundamental in projects of mechanisms, which justifies the accomplishment of this work. Meriam & Kraige [2] also state that the designs of gears, cams and many other moving parts of machines are largely kinematics problems, which demonstrates the importance of their study for engineering. Moreover, Norton [1] states that, in general, the analysis of forces and tensions cannot be done until questions about kinematics are resolved. Furthermore, Myszka [3] explains that most commercially produced mechanisms have one degree of freedom. For these reasons, three distinct mechanisms with one degree of freedom were chosen to be analyzed.

Thus, this work presents the kinematic analysis of some components of three different mechanisms with subsequent validation. All analysis were first performed using SolidWorks and later validated by comparing the results with values obtained by codes developed in MATLAB. Along with this, in some cases analytical calculations were also performed as another method of verifying the accuracy of the results observed in SolidWorks and MATLAB, thus ensuring that the observed results are correct.

2 Methodology

The mechanisms analyzed were a four-bar mechanism, a quick return mechanism, and a slider-crank mechanism. The 3d modeling and the union of the elements were done in the SolidWorks software. Subsequently, were performed analysis in five different crank rotation frequencies in each mechanism. They were done using the SolidWorks "motion study" feature, whereby displacement, velocity and acceleration values were collected. For all analysis, the SolidWorks was configured to generate one frame per degree of crank rotation. Then, similar research was carried out using MATLAB codes, which afforded comparison and validation of the results.

2.1 Four-bar mechanism

Firstly, the four-bar mechanism was analyzed. Lengths of 250 mm, 225 mm, 150 mm, and 100 mm were used for the frame, coupler, rocker and crank, respectively, all shown in Fig. 1. Using the SolidWorks, analysis in frequencies from 11 Hz to 15 Hz for the crank rotation were done, generating graphs of kinematic parameters.

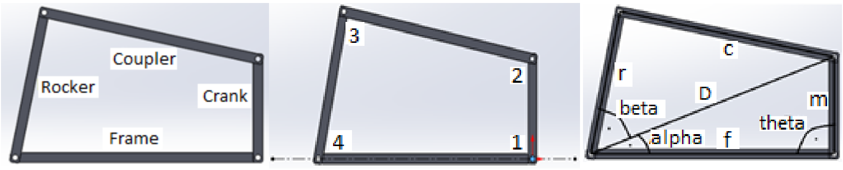

Figure 1. Four-bar mechanism and their links, number of joints, and parameters of the eq. (1), eq. (2) and eq. (3).

Then, a MATLAB code was developed to determine the kinematic values of rotation of the coupler. The law of sines and the law of cosines were used to define the relations between the angle of rotation of the crank (θ) and the sum of α and β, besides the distance from the joint 2 to joint 4 (D) in function of these angles. These formulas are described in the eq. (1), eq. (2) and eq. (3) below, all shown in Fig. 1.

$$\alpha = \sin^{-1}(((\sin\theta)\cdot m)/D) \quad (1)$$

$$\beta = \cos^{-1}((r^2 + D^2 - c^2)/(2\cdot r\cdot D)) \quad (2)$$

$$D = \sqrt{f^2 + m^2 - (2\cdot f\cdot m\cdot\cos\theta)} \quad (3)$$

Equations 1,2 and 3 allowed to find the angular position and the instant center of rotation, which was useful to set up the code to calculate the angular velocity and acceleration of the coupler. Later, the results were compared with those found in SolidWorks, validating them. To develop the MATLAB code, it was used the instant center achieved extending the rocker and the crank. Finally, the SolidWorks values were compared with the analytical results, that was found positioning the rocker and crank parallel (with the instant center in the infinite).

2.2 Quick return mechanism

The quick return mechanism dimensions, as well as the formulas used in the MATLAB code, were defined from Monkova & Monka [4]. The rocker had 400 mm, the coupler 150 mm, and the crank 100 mm. Frequencies from 3Hz to 7Hz for the crank rotation were used, and the rocker and the slider were analyzed. The Fig. 2 depicts the model. According to Norton [1], the time ratio defines the degree of quick return. Here it was found using the slider graphic of displacement in function of time, got from the SolidWorks. The MATLAB code analyzed the kinematic parameters of the slider. The eq. (4) was found from eq. (5) and eq. (6), and represents the position of the element, from which the velocity and acceleration were found by derivation. All symbols are shown in Fig. 2.

$$Xc = Xb - \sqrt{r3^2 - (b - Yb)^2} \quad (4)$$

$$Xb = [r2\cdot\sin\,(tan^{-1}((c + r1\cdot\sin\theta)/(h + r1\cdot\cos\theta)))] - c \quad (5)$$

$$Yb = [r2\cdot\cos(tan^{-1}((c + r1\cdot\sin\theta)/(h + r1\cdot\cos\theta)))] - h \quad (6)$$

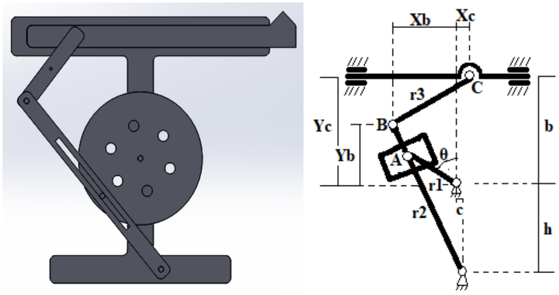

Figure 2. Quick return mechanism used in the SolidWorks, and the parameters of the eq. (4), eq. (5) and eq. (6)

2.3 Slider-crank mechanism

The third mechanism is the slider-crank. The dimensions were taken from data of the LS3 engine, used by Chevrolet [5]. The slider, coupler, and crank are, respectively, the piston, connecting rod, and the crankshaft of the LS3 engine. As frequencies of analysis, were used 44Hz, 66Hz, 88Hz and 110Hz, being 110Hz equal to 6600RPM, the maximum frequency indicated by Chevrolet [5]. The analysis of this mechanism allowed to found the kinematic parameters of the slider (piston). The Fig. 3 illustrate the mechanism designed in SolidWorks.

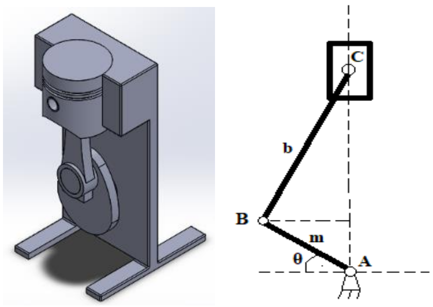

Figure 3. Slider-crank mechanism patterned in SolidWorks, and the parameters of eq. (7), eq. (8) and eq. (9)

To develop the MATLAB code for this mechanism, and then validate the results, were utilized the eq. (7) and its derivatives (eq. (8) and eq. (9)). The extreme values found and the shape of the graphics were compared with those obtained from SolidWorks. The Fig.3 shows the parameters utilized in the eq. (7), eq. (8) and eq. (9).

$$AC = (m \cdot \sin\theta\,) + \sqrt{BC^2 - (m \cdot \cos\theta)^2} \tag{7}$$

$$v = \dot{AC} \tag{8}$$

$$a = \ddot{AC} \tag{9}$$

3 Results

3.1 3.1 Four-bar mechanism

In Tab.1 below there are the coupler kinematic parameters found in the SolidWorks. The MATLAB values were similar to those of the SolidWorks. The maximum angular velocities for 11 and 15 Hz had differences of 0.01 Rad/s and 0.12 Rad/s, respectively, equivalent to 0.02% and 0.19%. The maximum angular accelerations for these frequencies, had differences of 1,04 and 0,42 Rad/s², or 0.02% and 0.005%. Finally, the max. angular position variation was 52,78º. The Fig. 4 represents the angular velocity and acceleration curves in function of time. Lastly, it was noticed that there is no possibility of locking, due to the fact that there is no dead center.

Table 1. Extreme values of velocity and acceleration for the coupler found in SolidWorks

Coupler				
Frequency (Hz)	*ω* maximum (rad/s)	*α* maximum (rad/s²)	*v* maximum (m/s)	*a* maximum (m/s²)
11	46.33	4799.27	7.52	783.82
15	63.18	8924.4	10.25	1457.55

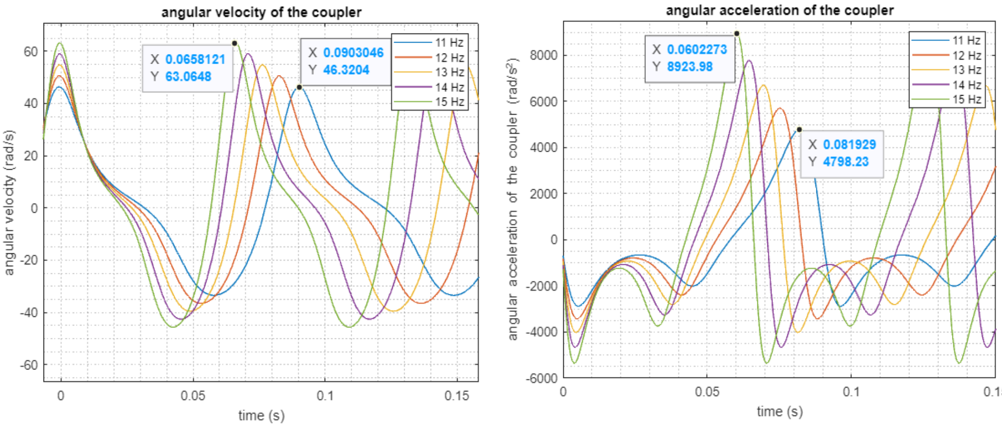

Figure 4. Angular velocity curve and angular acceleration curve found in MATLAB

3.2 Quick return mechanism

For the quick return mechanism, the SolidWorks provided values of maximum velocity and acceleration for the cutting tool and for the rocker on the chosen frequencies. Some results can be seen in the Tab. 2.

Table 2. Velocity and acceleration extremes for the cutting tool and the rocker found in the SolidWorks

	Cutting tool		Rocker	
frequency (Hz)	*v* maximum (m/s)	*a* maximum (m/s²)	*ω* maximum (rad/s)	*α* maximum (rad/s²)
3	7.38	195.13	18.13	453.42
7	17.23	1062.52	42.3	2468.51

The time ratio found by the SolidWorks was 2, so it takes twice as long to turn back than to advance. Moreover, from the MATLAB data and for the maximum frequency, it was realized that the maximum cutting tool velocity was the same found in the SolidWorks, while the results for acceleration had a difference of 0.01m/s², or 0.00094%. For the minimum frequency, these differences were 0.01m/s and 0.028m/s², respectively, or 0.081% and 0.014%. The Fig. 5 depicts the velocity and acceleration of the cutting tool in function of time, exposing the extreme values found for the curves of maximum and minimum frequency.

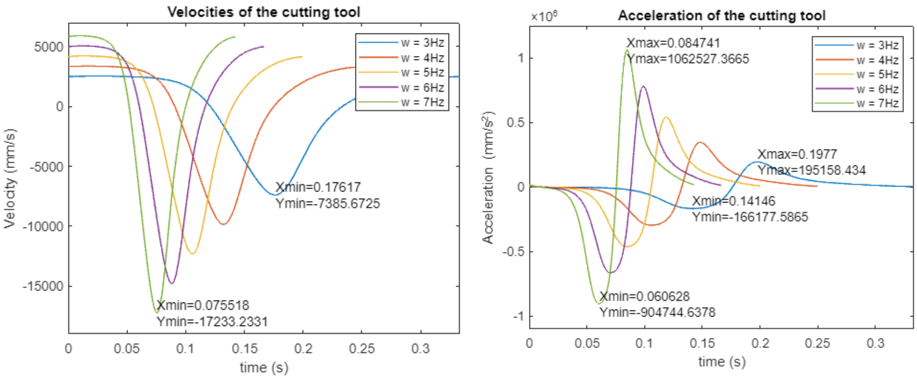

Figure 5. MATLAB Curves of velocity and acceleration of the cutting tool in function of time.

3.3 Slider-crank mechanism

The extreme values of velocity during the descent and ascent were the same, for all frequencies. Further, the maximum values of acceleration occurred during the descent. The Tab. 3 illustrates the extreme values for all frequencies, analyzed in the SolidWorks. It was seen the similarity in the curves format generated by the SolidWorks and by the MATLAB. For the maximum frequency, the maximum difference between values of velocity and acceleration were 0.004 m/s and 7.58 m/s², or 0.01% and 0.03%. Moreover, the Fig. 6 represents the graphs provided by the MATLAB for the slider, with extreme values depicted for the curves of 22Hz and 110Hz.

Table 3. Extremes of velocity and acceleration found in SolidWorks.

Slider (Piston)		
Frequency (Hz)	*v* maximum (m/s)	*a* maximum (m/ s²)
22	6.63	1139.9
66	19,9	10259,41
110	33.17	28497.18

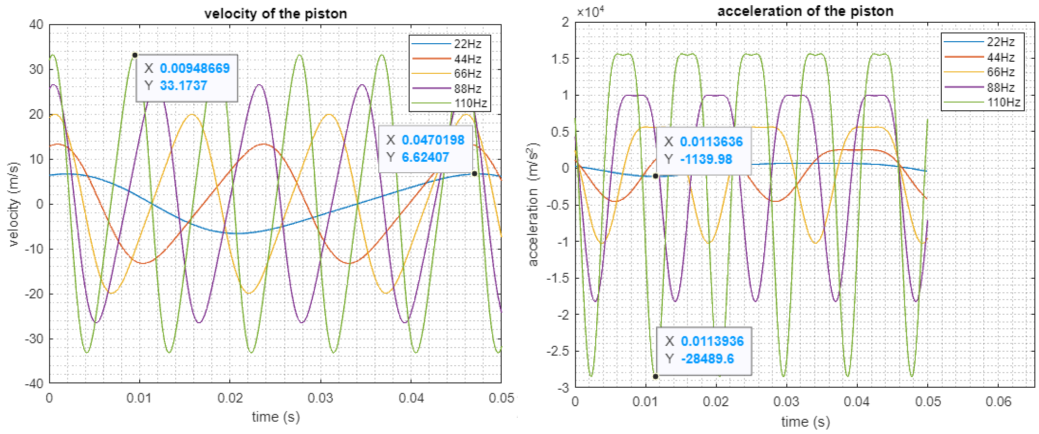

Figure 6. Graphics of velocity and acceleration of the piston given by the MATLAB code

4 Conclusions

From the analysis done, was possible to find multiple kinematic values and ensure that they were correct, due to the fact that the results obtained were very close. Therefore, it can be said that the SolidWorks values – simpler to be achieved, because does not need programming knowledge – are extremely reliable, when found using 1 frame per degree of rotation of the crank. Furthermore, the use of these tools proved to be useful to determine some details, as the time ratio of the quick return mechanism. Lastly, was possible to show in practice that the combination of SolidWorks and MATLAB is an excellent way to discover if kinematic data of mechanisms of one degree of freedom are correct.

5 References

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