Universidad de los Andes
Department of Mechanical Engineering

Analysis of a Quick Return Mechanism: Application Guide

Annex to *A Design of Machinery Learning Activity to develop Critical Thinking*

David Sanchez-Londono
Sofia Posada-Ceron
Giacomo Barbieri
Carlos Francisco Rodriguez

2021

1 Background: March 2020 implementation

The following activity was implemented in a 2020 Dynamics of Machinery course at the *Universidad de los Andes*. Students were told to work individually on the activity, given that the COVID-19 lockdowns had just started, and individual work was deemed to be simpler from an IT point of view at the time. Previous versions of the activity had been worked on in groups of two students however, which is reflected in the included implementation suggestions and guidelines.

Regarding this specific 2020 implementation, students were given around 9 hours of work time to complete the activity, which included 3 hours of class time and (in theory) 6 hours of individual, outside-class work time. They could use more or less of their own time as they needed. An *a posteriori* survey indicated how much time the students ended up needing to complete the activity:

	N	%
3 - 6 hours	3	7.1%
6 - 9 hours	12	26.2%
9 - 12 hours	19	45.2%
More than 12 hours	8	21.4%

Table: Time the students say to have spent on the activity, out of 42.

Results show that students should be given more than 9 hours to complete the activity, which is reflected in the guidelines below.

Regarding regularly-asked questions, students tended to inquire more about the use of technological tools (Excel, Inventor) as opposed to questions about Dynamics of Machinery itself. A greater emphasis on the use of such tools has been given during lectures since then.

2 Guidelines and suggestions

- *Groups:* This activity should be presented to students to be solved either as individuals or in groups of two or three students.
- *Time:* The students should be initially given around 9 hours to complete the activity, including time in and out of the regular lecture sessions. This time should be extended to 12 or 15 hours depending on the students' pace - a translation from expected work hours to calendar days depends on the course's intended time intensity.
- *Lectures:* Class time dedicated to the activity should be spent, first, on presenting the activity to the students. After that, all class time should be spent in Questions and Answers sessions and time for working individually / in small groups.

- *Inventor assembly:* Students should be supplied with a pre-assembled Inventor model of the problem to perform kinematics and kinetics simulations.

Regarding the Excel template: Students should be supplied with an Excel template of the exercise. The template should contain these main features: **a)** blank spaces where the geometric values can be put, **b)** blank spaces for kinematics and kinetics calculations (see the figure below for an example of such a template), and **c)** a separate sheet where exported Inventor data can be pasted to compare the Excel and Inventor models.

Saw mass	3	kg
C (friction)	10	Ns/m
Cutting force	20	kgf
Return force	5	kgf
w_motor	200	rpm
R	0.08	m
L	0.6	m
D	0.16	m
H	0.3	m
J	0.3	m

Alpha (deg)	Alpha (rad)	Time (s)	Phi (rad)	l_a (m)	Beta (rad)	⋯
0						
1						
2						
3						
4						
5						⋯
6						
7						
8						
9						
10						
⋮	⋮	⋮	⋮	⋮	⋮	⋱

Figure: Example of how an Excel template for the activity might look like. Note the presence of variables and constants in a separate column.

For the blank spaces for kinematics and kinetics, at least these columns have to be present:

- *Position Analysis*: $Alpha$ (degrees), $Alpha$ (radians), $Time$, Phi, l_a (variable distance from O_2 to A), $Beta$, x_S (position of the saw S in the x axis).
- *Velocity Analysis*: $dPhi$, dl_a, $dBeta$, v_S (velocity of the saw S in the x axis), v_{Sdiff} (same velocity but calculated numerically from the position column), m_A (mechanical advantage between the force output and the torque input), $abs(m_A)$ (absolute value of m_A).
- *Acceleration Analysis*: a_{Sdiff} (acceleration of S calculated numerically from the velocity column).
- *Kinetics*: F_{load} (value of either the cutting force or the returning force, depending on current direction of motion), $F_{friction}$ (value of the viscous friction force), $F_{inertia}$ (value of the force required to counter the inertia of the saw, calculated by multiplying m_S times a_S), F_{out} (resulting force from the sum of all horizontal forces on the saw), T_{in} (approximation of the required torque using the output force and the mechanical advantage).
- *Power Analysis*: P (Power requirement given the input torque and the constant rotational velociy)

Analysis of a Quick Return Mechanism

Universidad de los Andes
Department of Mechanical Engineering
IMEC-2543 Dynamics of Machinery

The goal of this activity is for you to resize some elements of the mechanism of a reciprocating mechanical saw that has 20 kgf of cutting capacity. For this, you must work using Excel and Inventor. The setting of the mechanism is shown below:

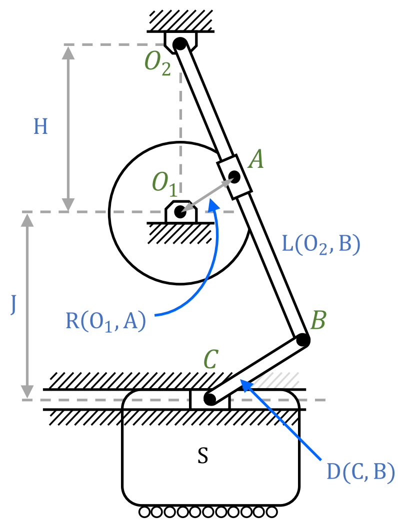

Figure 1: Mechanism of a reciprocating mechanical saw.

The mechanism consists of a crank (length R) that drives an oscillator (length L), a connecting rod (length D) and a slider (saw S). The mechanism is moved by the action of the crank.

The mechanism is driven by a $1.5HP$ DC motor that rotates at $200RPM$ counterclockwise. The mechanism only generates the cutting action when the saw is moving to the right.

The saw must fulfill the requirement:

- Minimum trajectory of $0.3m$

In addition, the following restrictions must be fulfilled since you want to limit the size occupied by the mechanism:

- $(\Phi_{max} - \Phi min) \rightarrow L_2 + D_2 <= 0.8m$
- $R_2 <= J_2$
- $H_2 + R_2 <= L_2$
- $H_2 + J_2 <= L_2$

For your calculations assume the following:

- With the saw S being an exception, all the rods have negligible mass. There is no relevant friction between their unions.
- The mass of saw S is 3 kg.
- When the saw is moving right the cutting force is constant and has a value of 20 kgf. When the saw is moving left the cutting force is 5 kgf.
- Consider that there is a friction force between the saw and the support surface, you can model it as a viscous friction with a coefficient of $10Ns/m$.

You have to decide the values of the parameters R, L, D, H, J so that the energy consumption of the mechanism is minimized. Thus, you have to optimize the function:

$$ObjectiveFunction : Average(P_{in}) \tag{1}$$

Your selection must respect:

1. The restrictions enunciated above,
2. The trajectory requirement, and
3. The motor power capacity

Mechanism Dynamics

To calculate the mechanism dynamics you will find an Excel template file. This document has a section with blank columns for the kinematics and kinetics of the mechanism. There is another section in which you can change design parameters and verify the chosen solution. Finally, you will find a separate sheet in which you can compare the analytic model with the dynamic simulation. In addition, an Inventor assembly will be available for the validation of the analytic model through a comparison with the dynamic simulation. For the initial validation, consider that the excel template and the Invetor assembly have the same geometric parameters.

The names of the angles and positive directions of the axis are specified in the image shown below (2). Follow these conventions when building the analytical model. Consider the origin of the coordinate system in O_2.

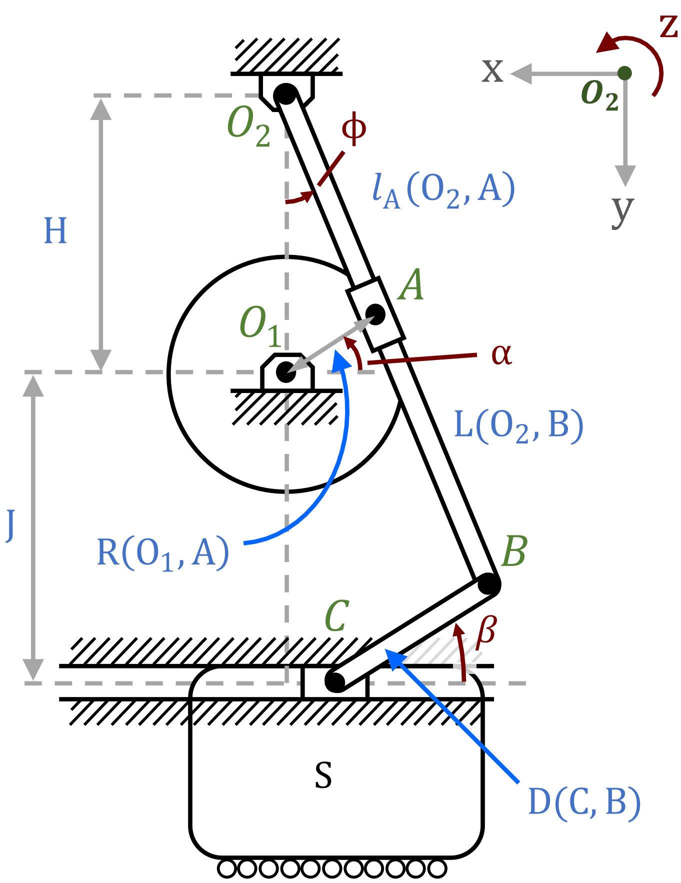

Figure 2: Angles and positive directions in the reciprocating mechanical saw.

Evaluation

1. *Position Analysis*: analytically calculate the position analysis of the mechanism by using the provided Excel template. Use an Inventor sketch to verify the accuracy of the analytical model.
2. *Velocity Analysis*: analytically calculate the velocity analysis of the mechanism in the Excel template. Use a numerical derivative to verify the accuracy of the analytical model.
3. *Mechanical advantage*: analytically calculate the value of the mechanical advantage in Excel.
4. *Acceleration Analysis*: numerically calculate the acceleration of the saw in the Excel template.
5. *Dynamic simulation of kinetics*: implement a dynamic simulation of the mechanism to validate the analytical model. Use inventor to calculate the position, velocity and acceleration of the saw and fill in the Inventor blank spaces of the Excel template to compare the analytical and Inventor values. **Note**: properly select the number of Inventor simulation steps to get as many values as you got in Excel - this will simplify the comparison process.
6. *Forces on the saw*: Calculate the cutting/return force, friction force, required force due to inertia, and resulting F_{out} in the Excel template.
7. *Torque approximation using m_a*: use the mechanical advantage relationship to calculate the torque that the crank requires.
8. *Validation of the "black box" hypothesis*: considering that all intermediate links lack inertia or resistive forces, we can very precisely calculate the required input torque by using the mechanical advantage m_a and seeing the mechanism as a "black box". To validate this hypothesis, we will compare this torque found through the mechanical advantage and the torque calculated through the Inventor dynamic simulation. Use Inventor to calculate the required input torque, and fill in the Inventor blank spaces of the Excel template to compare the analytical and Inventor values. Furthermore, **record a video** of the simulation in motion. **Note**: Inventor does not allow zero mass links, so instead use a significantly small mass value.
9. *Motor power*: calculate the theoretical power that the input motor requires. Given that this is a DC motor, power is calculated using $P = T \cdot \omega$.
10. *Viable configuration*: modify the design parameters until you reach an acceptable solution (where the trajectory requirement, geometric constraints, and power constraint are all fulfilled).
11. *Bonus - Most efficient configuration*: you will obtain a score bonus depending on how optimal the mechanism is (in this case, how low the *mean power requirement through a single revolution* is).