Cyclic Knee Testing Mechanism

Subham Swastik Samal (ME16B045)

Guide: Dr. Sujatha Srinivasan

Department of Mechanical Engineering

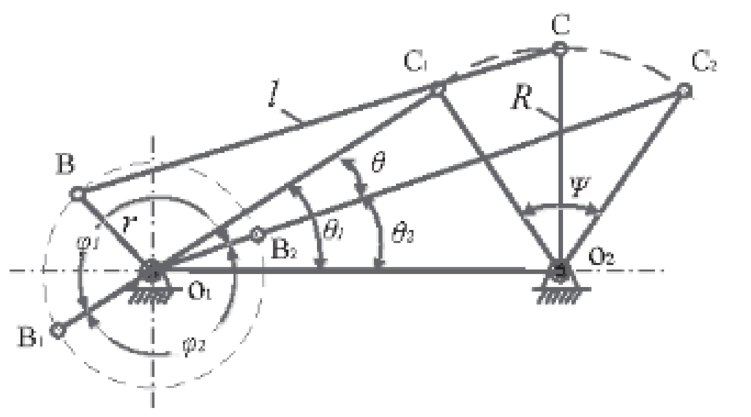
Indian Institute of Technology Madras

Introduction

- The usage of above knee prosthesis is extremely common among trans-femoral amputees, as it provides a higher mobility range and independence compared to wheelchairs.
- During walking cycle, knee joint prosthesis is subjected to cyclic loading which can cause failure due to fatigue, making it necessary to evaluate their life before recommending to users.
- This project analyses currently available knee-testing methods like knee simulators, which tend to have complex mechanisms with many actuators, and are unaffordable and heavy.
- Therefore, the project is aimed to develop a simple and compact single-actuated mechanism for knee-life testing.

Methodology

Crank-Rocker Mechanism Formulation



Standard procedure of designing crank-rocker mechanism[1]

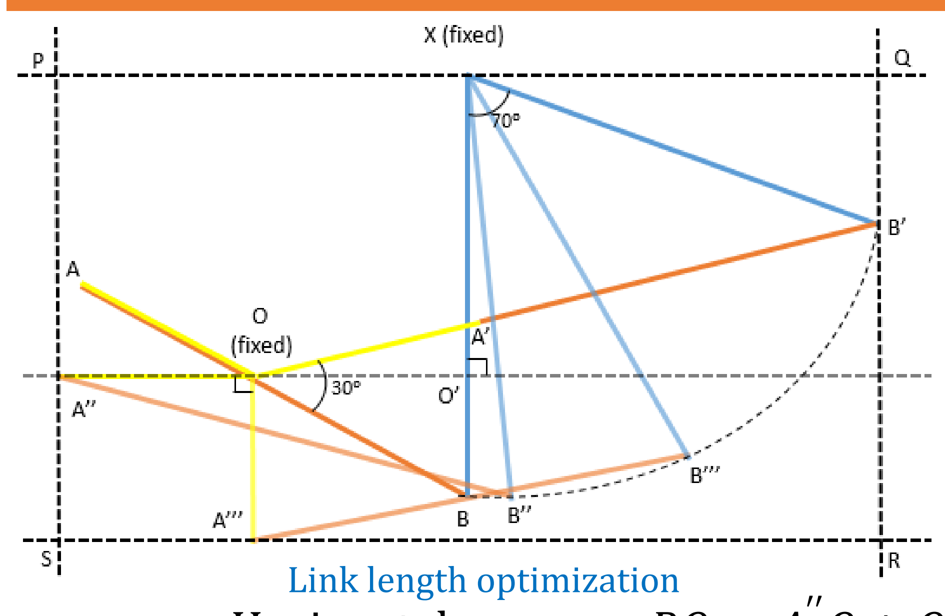
The rocker guides the motion of the shank, providing a range from complete extension to flexion by 70^0

$$\Rightarrow \psi = 70°$$

While in the swing phase of walking, the ratio of time taken for flexion and extension is about 4:3

$$\Rightarrow \theta = 30°$$

Optimizing link lengths for compact mechanism



Link length optimization

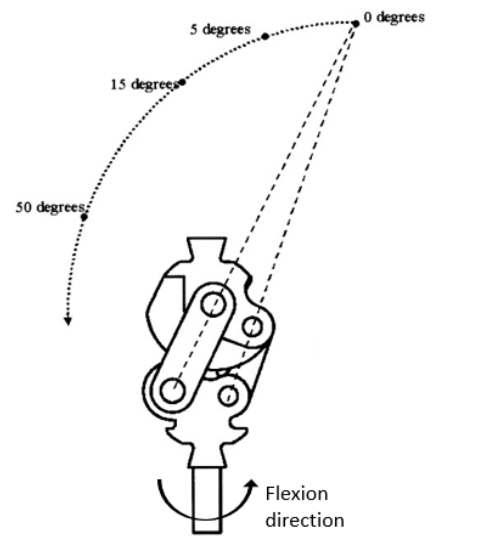
To make the mechanism compact, it was aimed to minimise the rectangular area swept by the mechanism in one complete cycle of motion.

$$\text{Horizontal sweep} = PQ = A''O + OO' + XB' * \sin(70)$$

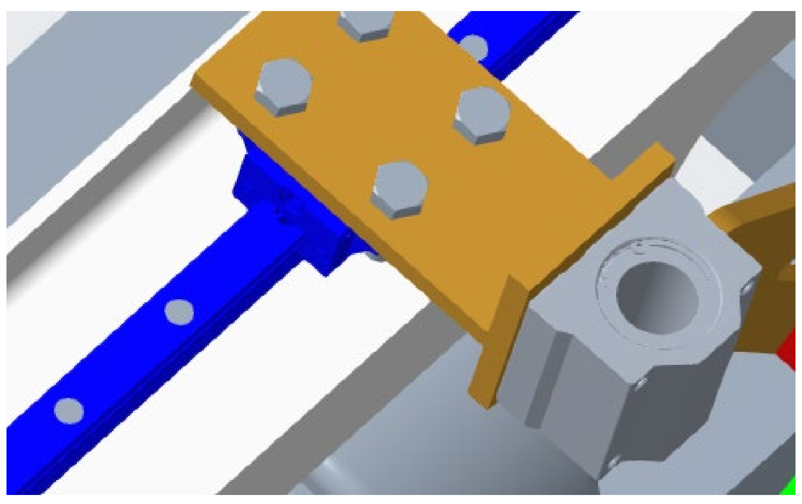
$$\text{Vertical sweep} = QR = \max(XB, XO' + OA''')$$

$$\text{Area swept} = (\textit{horizontal sweep}) * (\textit{vertical sweep})$$

Countering Polycentricity



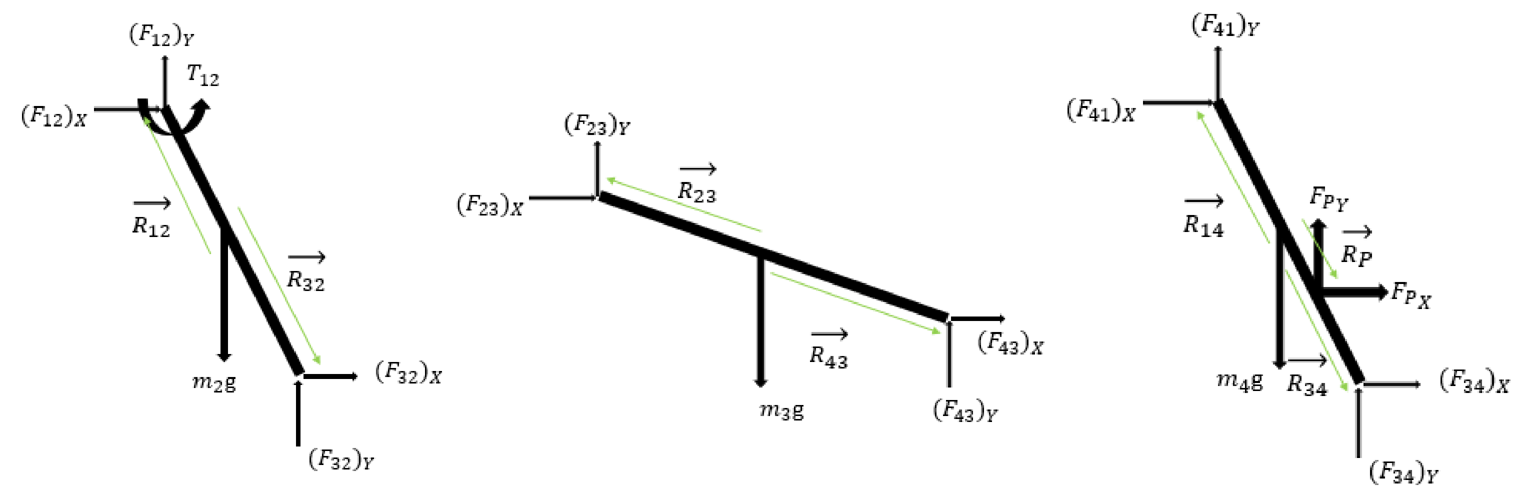
ICR in a polycentric knee[2]



Linear guide and bushing to provide 2 DOF for the moving ICR

- For polycentric knees, the position of the instantaneous centre of rotation changes with the knee configuration on the motion plane.
- The ICR, a point has 2 DOFs in the motion plane, which are accounted by the bushing (vertical) and the linear guide system (horizontal)

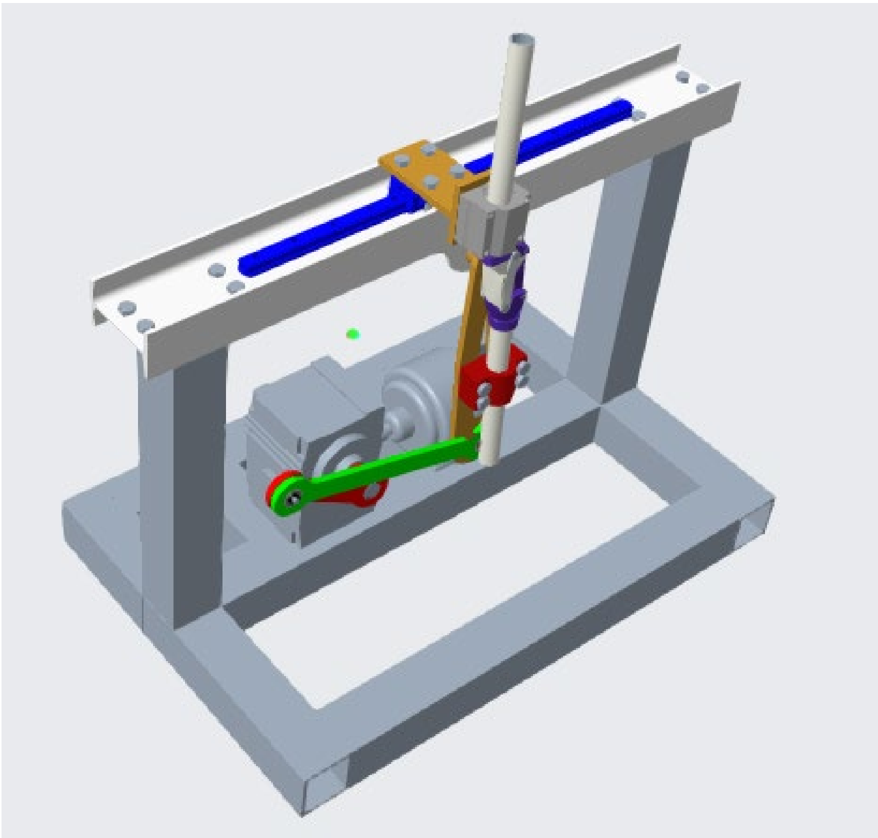
Calculation of forces and torques



FBD of crank, connecting rod and rocker (L-R)

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -R_{12Y} & R_{12X} & -R_{32Y} & R_{32X} & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & R_{23Y} & -R_{23X} & -R_{43Y} & R_{43X} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & R_{34Y} & -R_{34X} & -R_{14Y} & R_{14X} & 0 \end{bmatrix} * \begin{bmatrix} F_{12X} \\ F_{12Y} \\ F_{32X} \\ F_{32Y} \\ F_{43X} \\ F_{43Y} \\ F_{14X} \\ F_{14Y} \\ T_{12} \end{bmatrix} = \begin{bmatrix} m_2 a_{Gx_2} \\ m_2 a_{Gy_2} + m_2 g \\ I_{G_2}\alpha_2 \\ m_3 a_{Gx_3} \\ m_3 a_{Gy_3} + m_3 g \\ I_{G_3}\alpha_3 \\ m_4 a_{Gx_4} - F_{PX} \\ m_2 a_{Gx_2} - F_{PY} + m_4 g \\ I_{G_4}\alpha_4 - F_{PY}R_{PX} + F_{PX}R_{PY} \end{bmatrix}$$

Results and Discussion



3D CAD Model of the setup

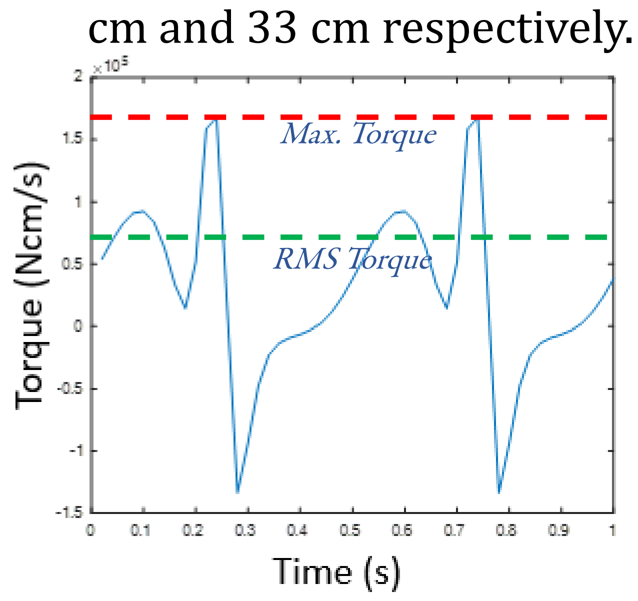
Gruebler's equation states that:

$$\mathbf{F = 3(n-1) - 2 * l - h}$$

So, no. of degrees of freedom(F) in mechanism = 3 *(8-1) – 2*10 – 0 = 1

Thus, a single actuator is required to run the setup

- Optimized lengths of the crank, connecting and rocker are 17cm, 35 cm and 33 cm respectively.

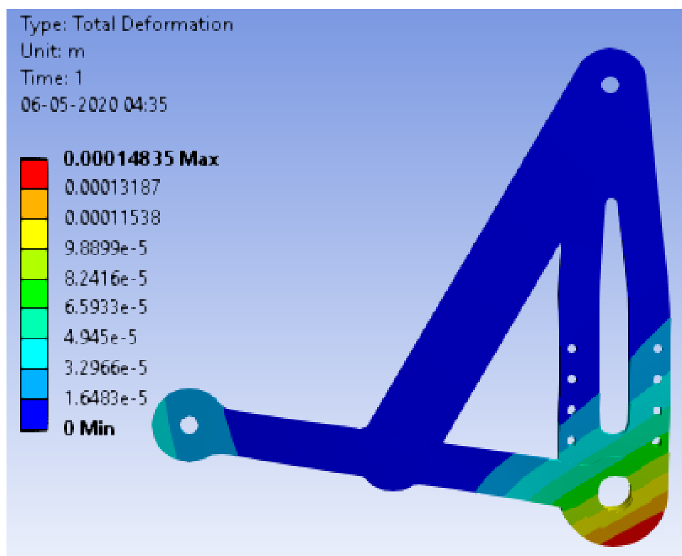


Rotating the crank at 120 rpm,

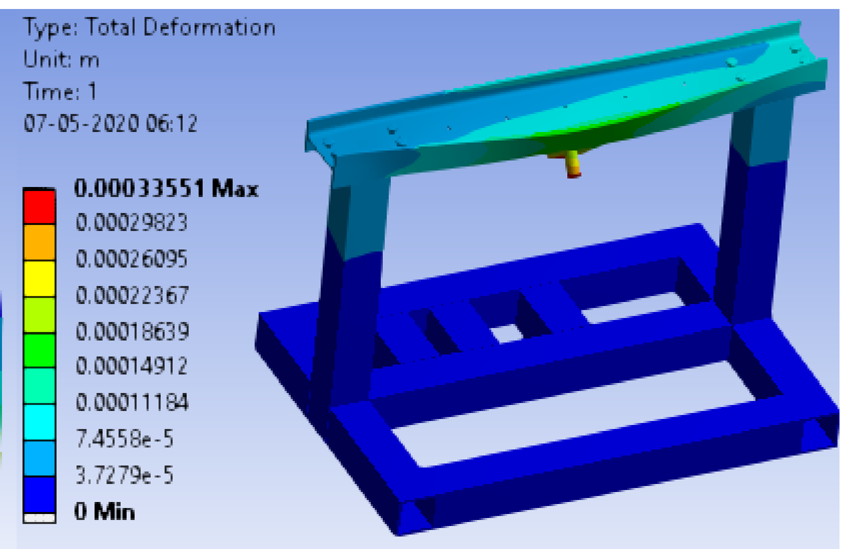
$$\text{RMS Torque} = \sqrt{\frac{\sum Torque_i^2 * time_i}{\sum time_i}} = 7.277\ Nm$$

Maximum Torque = *16.804 Nm*

Minimum required motor rating = **255.95 W**



Maximum deformation of links



Maximum deformation for frame

Conclusion and Future Scope

- A new technique for testing the walking longevity of prosthetic knee joints was developed by using a crank-rocker mechanism as a simulator for the swing phase of a walking gait cycle.
- Future work would involve manufacturing of the setup and testing available prosthetic knees to obtain their life.
- Modification of this technique to accommodate testing of the stance phase could be looked into, thus integrating both the phases to test the knees for the complete gait cycle using a single mechanism.

References

[1] Y. G. Liu and J. Sun, "Design of display retractile testing mechanism based on crank rocker," in *Proceedings of the 2015 10th IEEE Conference on Industrial Electronics and Applications, ICIEA 2015*, 2015, doi: 10.1109/ICIEA.2015.7334227.

[2] J. W. Michael, "Modern prosthetic knee mechanisms," in *Clinical Orthopaedics and Related Research*, 1999, doi: 10.1097/00003086-199904000-00006.