Cyclic Knee Testing Mechanism

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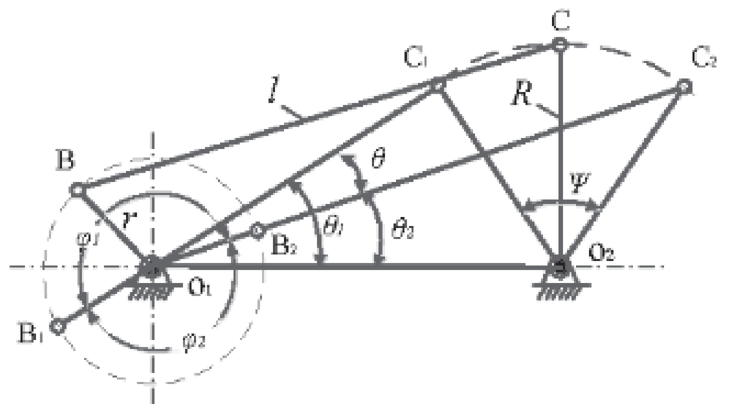
Introduction

- Above knee prosthesis usage is extremely common in transfemoral amputees due to higher mobility range, independence compared to wheelchairs
- Knee joint prosthesis undergoes cyclic loading during walking that can cause failure due to fatigue; necessitating prior knee-life evaluation
- Current knee-testing: knee simulators have complex mechanisms with many actuators; are unaffordable, heavy
- Project aim: To develop a simple, compact single-actuated mechanism for knee-life testing

Methodology

Crank-Rocker Mechanism Formulation



Standard procedure of designing crank-rocker mechanism[1]

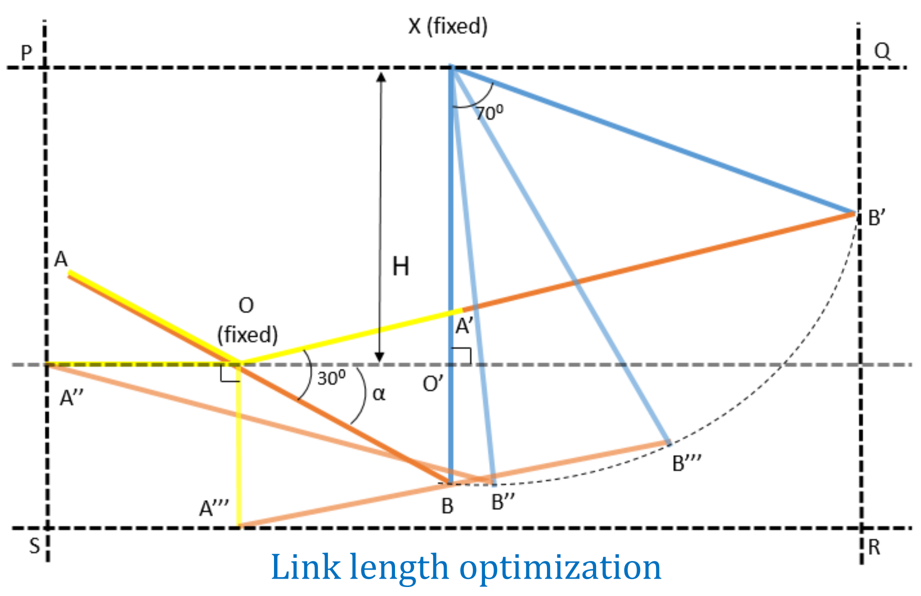
Rocker guides motion of the shank, providing a range from complete extension to flexion by 70^0

$\Rightarrow \psi = 70°$

In swing phase, the ratio of time taken for flexion and extension is ~ 4:3

$\Rightarrow \theta = 30°$

Optimizing link lengths for compact mechanism



Link length optimization

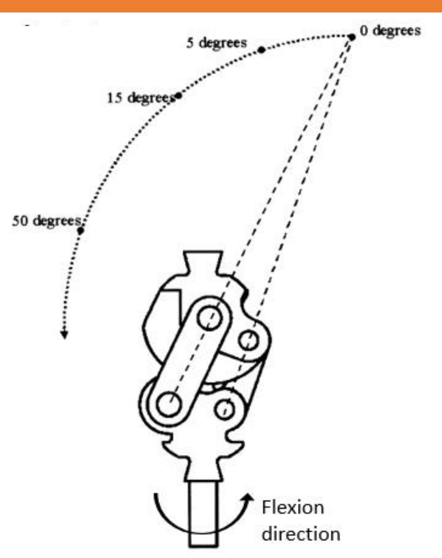
For compactness, it was aimed to minimise the rectangular area swept by the mechanism in one complete cycle of motion

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

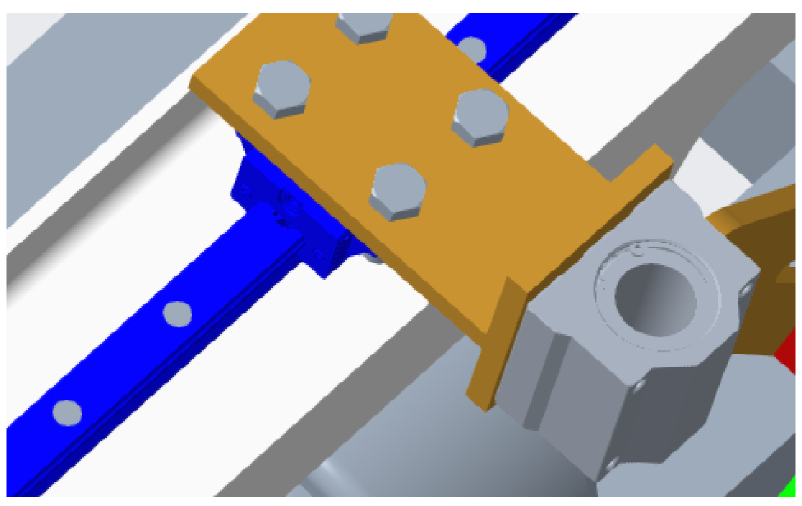
$$\text{Vertical sweep} = QR = \max(XB, XO' + OA''')$$

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

Accommodating Polycentricity



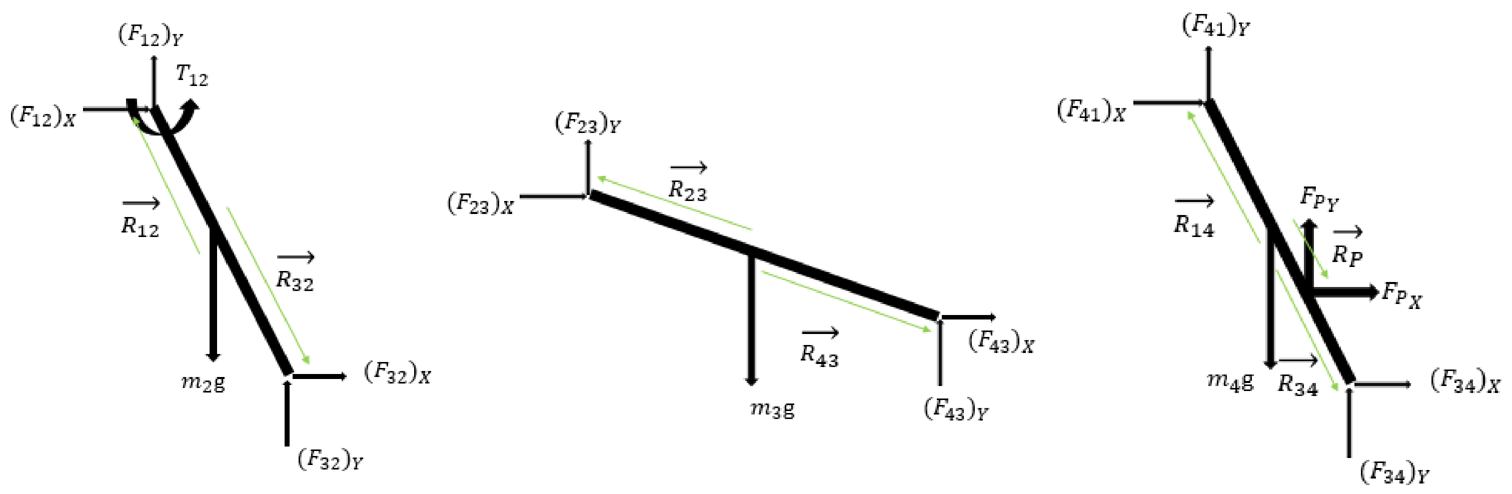
ICR in a polycentric knee[2]



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

- Polycentric knees: position of instantaneous centre of rotation (ICR) changes with knee configuration on motion plane
- ICR: 2 DOFs in motion plane; accounted by bushing (vertical) and linear guide system (horizontal)

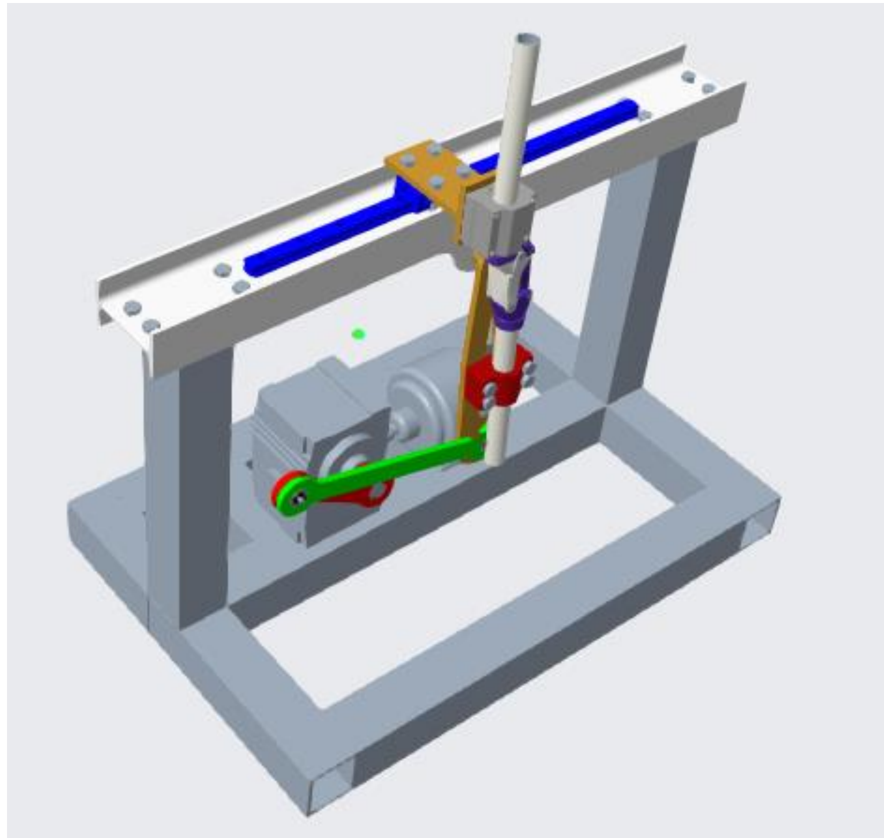
Calculation of forces and torques



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

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

Results and Discussion



3D CAD Model of the setup

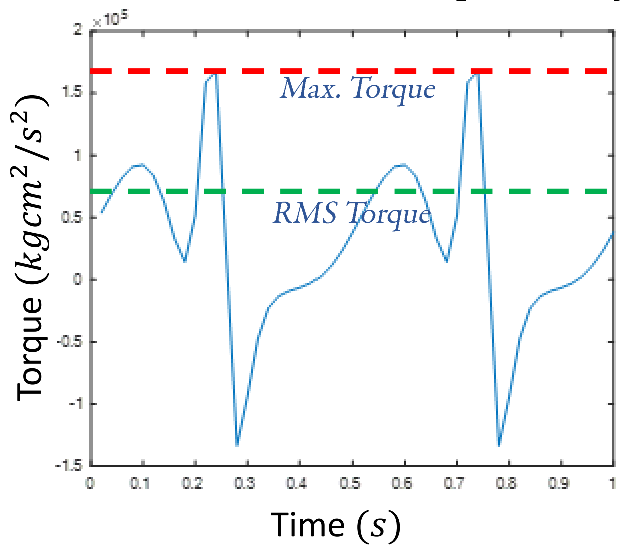
Degrees of freedom (DOF) in a mechanism (Gruebler's equation):

$$F = 3(n-1) - (2 * l) - h$$

DOF in this mechanism
= 3 *(8-1) – 2*10 – 0 = 1

Thus, a single actuator is required to run the setup

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

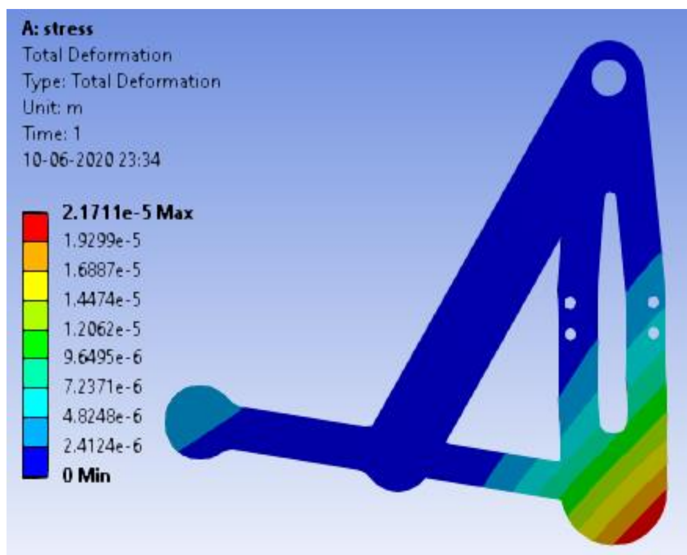


Rotating the crank at 120 rpm

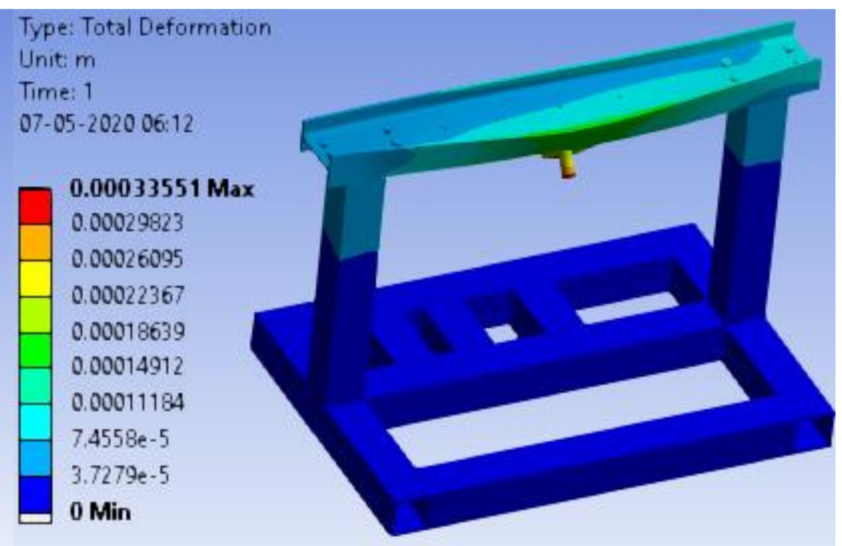
$$\text{RMS Torque} = \sqrt{\frac{\sum Torque_i^2 * time_i}{\sum time_i}} = 7.277\ Nm$$

Maximum Torque = *16.804 Nm*

Minimum required motor rating = 255.95 W



FEA (max. deformation) of links



FEA (max. deformation) of frame

Conclusion and Future Scope

- New technique developed to test walking longevity of prosthetic knees using crank-rocker mechanism as a swing phase simulator
- Next step: manufacturing of the setup and testing prosthetic knees to assess their life
- Future work: Modification of the technique to accommodate stance phase testing; integrating both swing and stance 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.