ME 232 S1 Project Report

Team 8
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SECTION 1: MECHANISM DESCRIPTION

Section 1.1: Basic Draft of the Mechanism

- The mechanism selected by us to perform the analysis is the **STRIDER (2-LEGGED).** The main components of the strider includes leg segments, leg joints and actuating system, which is most commonly driven using motor-gear system coupled to a crank in the mechanism. **The entire analysis is done in SOLIDWORKS 2023 (parts, assembly and motion assembly)**

References:
https://www.diywalkers.com/strider-linkage-plans.html
https://www.youtube.com/watch?v=oGE1tbno7j4

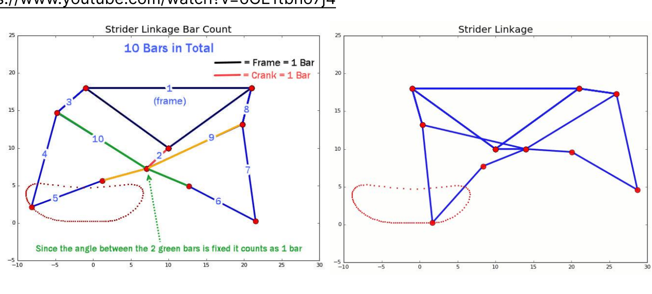


Fig 1: Images depicting the basing framework of the strider 2-legged mechanism and expected path of the output (leg)

Section 1.2: Description of the strider

- The Strider-2 leg mechanism is a **planar, bioinspired robotic system** designed to mimic the efficient and robust locomotion capabilities observed in animals like cockroaches and crabs. This mechanism incorporates a pair of multi-jointed legs, which enables them to adapt to various terrains and overcome obstacles effectively.
- This is total of **10 links** and **13 revolute joints** (including 1 ground link/frame) and **two gears for angular speed reduction** when high RPM motors are used. Usually, Lego blocks or laser cut acrylics are used to build the prototypes of the mechanism
- The **crank**, the only input to the mechanism is given the required torque to move the tow legs and **produce a walking motion**
- Mobility of the mechanism using **Grubler's equation** is **$3(n-j-1) + \sum f_i = 1$** for the strider

Advantages and Disadvantages:

▲ Bioinspired design allows for efficient and robust locomotion over challenging terrains
▲ Compliant actuation and articulated legs enable adaptability and obstacle negotiation
▼ Complex design and control system can increase manufacturing and maintenance costs
▼ Limited payload capacity compared to wheeled or tracked robots of similar size

Section 1.3: Applications of the mechanism

- Search and rescue operations in hazardous or rubble-filled environments, where its ability to navigate over rough terrain and obstacles would be advantageous.
- Exploration of extraterrestrial surfaces, such as the moon or Mars, where its adaptable locomotion could traverse uneven and unpredictable terrain.
- Infrastructure inspection tasks, like inspecting pipelines, bridges, or power lines, where its versatile mobility would allow access to hard-to-reach areas.
- Environmental monitoring in challenging natural environments, such as forests or mountainous regions, taking advantage of its terrain-traversing capabilities.
- Military or law enforcement applications, such as reconnaissance or surveillance in rugged or urban environments, benefiting from its stealthy and agile movement.

SECTION 2: CONTEXT OF USE

Section 2.1: History

- Origins in bioinspired robotics, drawing inspiration from nature's locomotion mechanisms
- **Early 2000s:** Research on cockroach-inspired locomotion at universities like Michigan and MIT
- **RHex robot** (University of Pennsylvania) - early hexapod robot mimicking cockroach movement
- Late 2000s: Boston Dynamics began developing Strider concept
- Initial Strider prototypes: Quadrupedal robots with articulated, compliant leg mechanisms inspired by crabs and insects
- Strider-2: Second major iteration with advanced leg mechanisms, improved terrain adaptability, and enhanced sensing
- Used as a research platform to explore legged locomotion, gait planning, terrain adaptation, and energy efficiency
- Tested in various applications: search and rescue, environmental monitoring, military reconnaissance
- Inspired further research and development in bioinspired robotics by other groups and companies
- Locomotion principles drawn from various animals like geckos, kangaroos, and humans

Section 2.2: Alternate mechanisms

There are similar walking mechanisms based on the number of links and path functions generated by the output link such as Strandbeest, TrotBot, Klann and Jansen Mechanisms

SECTION 3: MODEL SPECIFICATION OF USE

SECTION 3.1: Geometry and Material

Section 3.1.1: Dimensions of every link

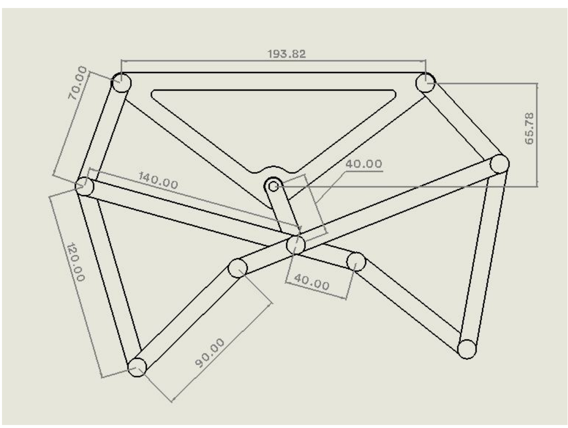


Fig 2: Front wireframe view of strider showing dimensions of all links

- Fig 2, shows the necessary and sufficient dimensions of the links to have a complete moving components of the mechanism. The dimensions could be scaled up or down
- The circles in the figure shows the revolute joints. Some of these dimensions where also obtained from trial and error. The dimensions of the link significantly affected the path of leg
- Also, note that, the link numbers are as per the Fig 1, showing that link 1 is the ground

Section 3.1.2 and 3.1.3: Masses and MOI of every component

Link Number	Mass in grams	MOI about centre of gravity ($kg.mm^2$)
1	29.344523	109.511
2	2.87	0.531
3 and 8	4.85	2.316
4 and 7	8.15	10.582
5 and 6	6.17	4.664
10 and 9	11.94	33.882

TOTAL MASS OF THE MECHANISM: 94.4345 grams

SECTION 3.2: Constraints on the motion of each component

- **Number of linkages:** n = 10
- **Number of joints:** n = 13
- **Total connectivity or total degrees of freedom for all joints:** $\sum f_i$ = 13 (All are planar revolute joints)
- From the **Gruebler's Equation** for finding mobility of whole mechanism:

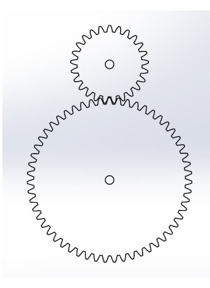
$$\boxed{m = 3(n-j-1) + \sum f_i \Rightarrow m = 1}$$

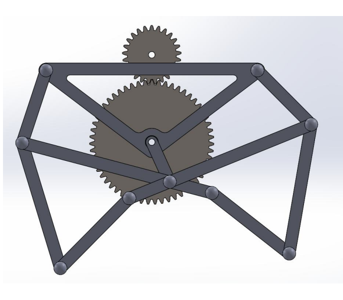
- Hence the output is dependent only on one input, that is crank rotation. These planar joints can be created using planar ball bearings or a door/window hinge like revolute joints.
- With reference to Fig 1, the link 1 is completely fixed, called ground/frame and **link 2 is the crank** and rotates complete 360⁰. The mechanism is configured in such a way that **it constrains the other links as rockers** (to move only between an angle/rotation range)

SECTION 3.3: Motion Transmission

SECTION 3.3.1: Driving Component

The motion transmission method used in the project to drive the mechanism is a pair of spur gears. The smaller gear drives the bigger one. The figure of the meshed gears and its properities are mentioned below:



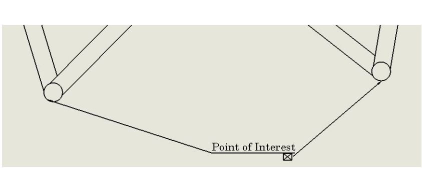


Gear Properties	Gear 2	Gear 1
Module (mm/tooth)	2	2
Pitch Diameter (mm)	110	50
Pressure Angle (degrees)	20	20
Shaft diameter (mm)	6	6
Number of teeth	55	25
Face width of gear (mm)	6	6

Note that Gear 1 is driving gear and gear 2 is the driven gear and hence velocity ratio is 5/11 = 0.454

SECTION 3.3.2: Component that gives output of interest

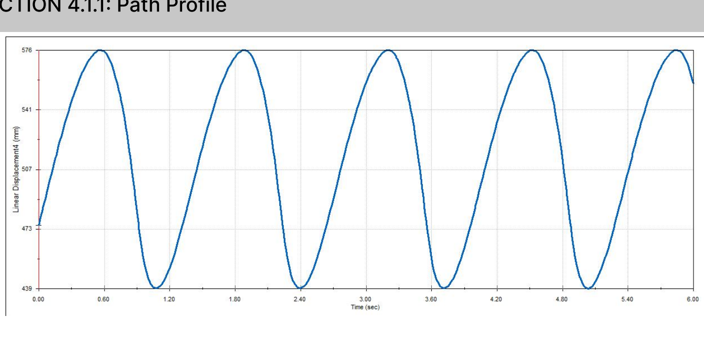
- The two legs of the mechanism are the components/links that are designed to generate certain path to take. In reference to the figure 1, joints of link (5, 4) and (6,7) is the points of interest.



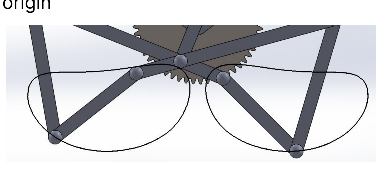
SECTION 4: KINEMATIC SIMULATION

SECTION 4.1: Output Component

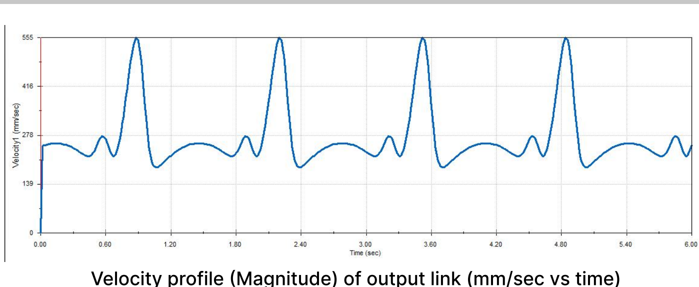
SECTION 4.1.1: Path Profile



- The black stroked lines in the figure below shows the path profile/path traced by the points of interest in a 6 seconds motion analysis in SolidWorks where the crank is given constant angular velocity (Rotary Motor). The profile above is the displacement profile measured wrt to origin
- **Input angular velocity:** 100 RPM

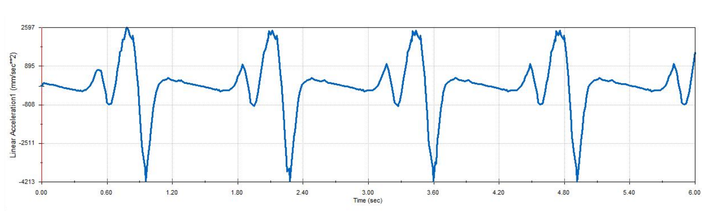


SECTION 4.1.2: Velocity Profile

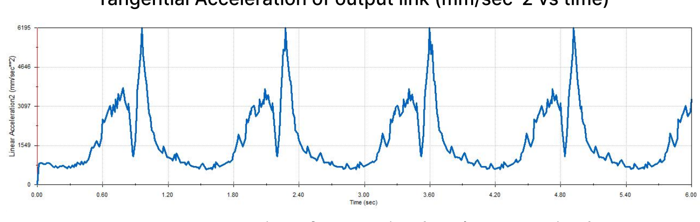


Velocity profile (Magnitude) of output link (mm/sec vs time)

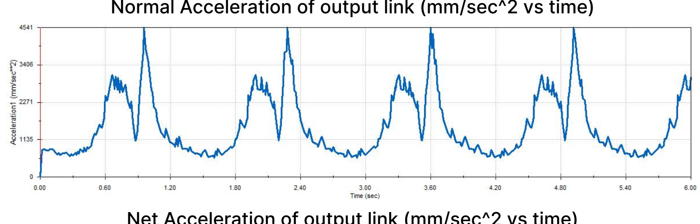
SECTION 4.1.3: Acceleration Profile



Tangential Acceleration of output link (mm/sec^2 vs time)



Normal Acceleration of output link (mm/sec^2 vs time)

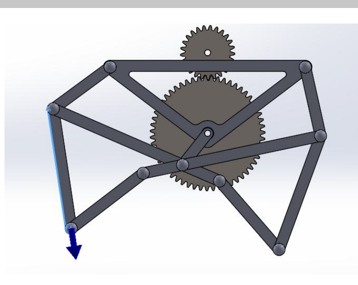


Net Acceleration of output link (mm/sec^2 vs time)

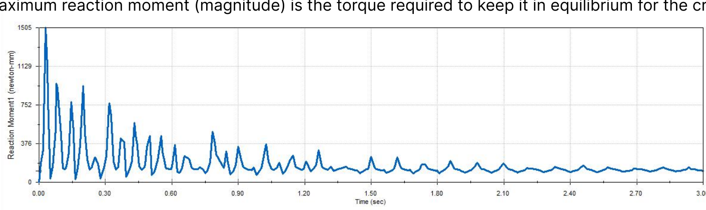
SECTION 4.1.4: Comments

- From the graph of 4.1.1, the path of both the legs/points of interests are identical, but at different times both will be at different positions from the origin
- Maximum velocity in magnitude went up to 555 mm/sec
- Maximum Normal acceleration: 6.195 m/sec^2
- Maximum Tangential acceleration: 2.6 m/sec^2
- Maximum acceleration (magnitude): 4.541 m/sec^2
- One can see periodicity in the graphs verifying same results for multiple rotations. Also, the accelerations graphs contain sudden drops and rises, where significantly large amount of jerks would be generated

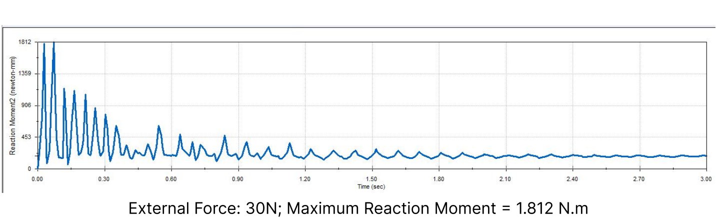
SECTION 5: STATIC FORCE ANALYSIS



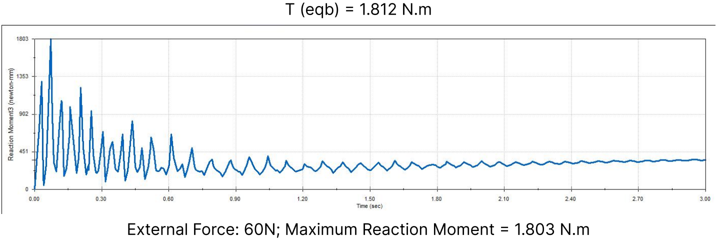
The force is applied at the output leg point and in blue arrowed direction
Maximum reaction moment (magnitude) is the torque required to keep it in equilibrium for the crank



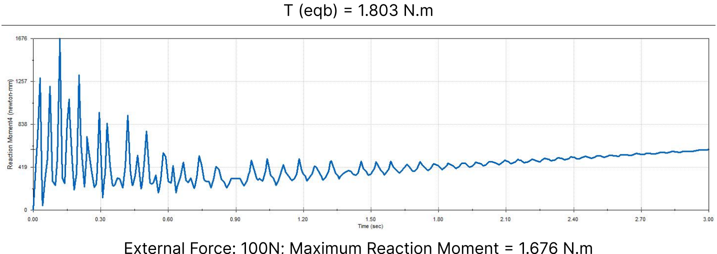
External Force = 20N; Maximum Reaction Moment = 1.505 N.m
T (eqb) = 1.505 N.m



External Force: 30N; Maximum Reaction Moment = 1.812 N.m
T (eqb) = 1.812 N.m



External Force: 60N; Maximum Reaction Moment = 1.803 N.m
T (eqb) = 1.803 N.m



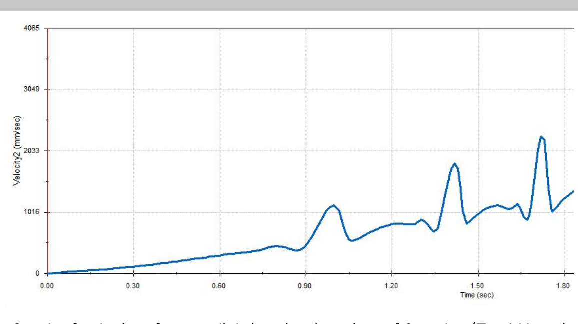
External Force: 100N; Maximum Reaction Moment = 1.676 N.m
T (eqb) = 1.676 N.m

SECTION 6: DYNAMIC FORCE ANALYSIS

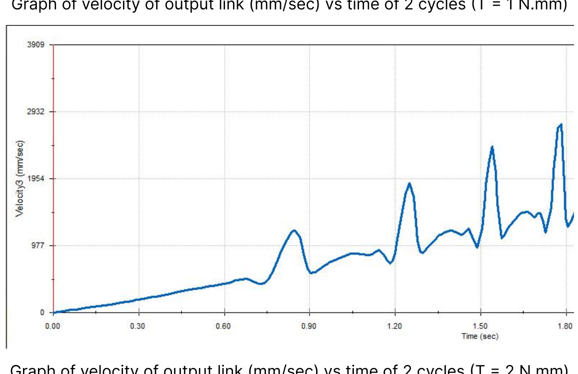
SECTION 6.1: Section 6.1.1 and Section 6.1.2

- In this section, the input external torque to the crank is given as 1 N.mm in anticlockwise direction and the graphs of magnitudes velocity and acceleration vs time(for two cycles) of the output point in observed
- Then for the second time the input external torque is doubled and hence 2 N.mm is given to crank. The results obtained through graphs are then observed and compared

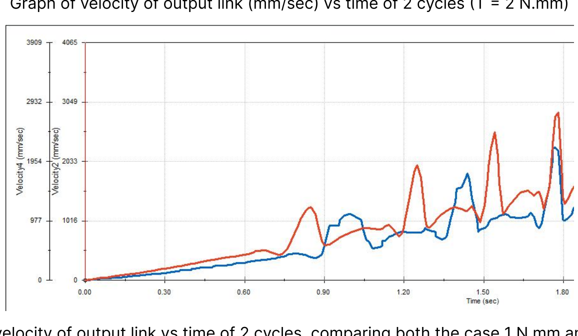
VELOCITY PLOTS



Graph of velocity of output link (mm/sec) vs time of 2 cycles (T = 1 N.mm)

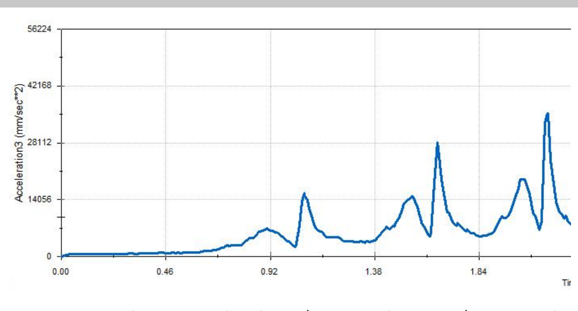


Graph of velocity of output link (mm/sec) vs time of 2 cycles (T = 2 N.mm)

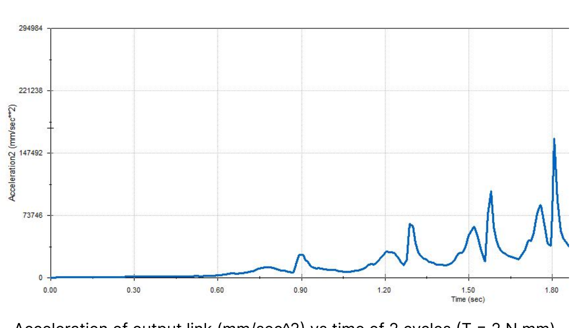


Graph of velocity of output link vs time of 2 cycles comparing both the case 1 N.mm and 2 N.mm

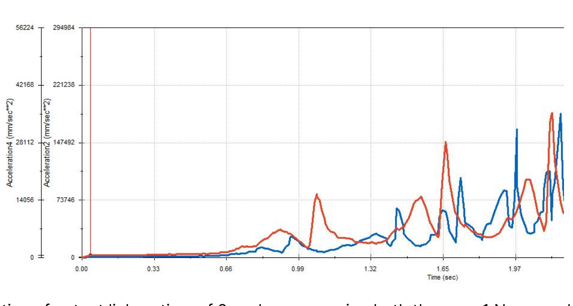
ACCELERATION PLOTS



Acceleration of output link (mm/sec^2) vs time of 2 cycles (T = 1 N.mm)



Acceleration of output link (mm/sec^2) vs time of 2 cycles (T = 2 N.mm)



Acceleration of output link vs time of 2 cycles comparing both the case 1 N.mm and 2 N.mm

OBSERVATIONS AND COMMENTS ON THE PLOTS

- In the case where torque of 1 N.mm given to crank, the output link has
  - Maximum magnitude of velocity: 2.05 m/s
  - Maximum magnitude of acceleration: 35.14 m/s^2
- In the case where T = 2 N.mm given to crank, the output link has
  - Maximum magnitude of velocity: 2.909 m/s
  - Maximum magnitude of acceleration: 147.5 mm/s^2
- Hence, the values of velocity and acceleration is higher in the case when torque is 2 N.mm than 1 N.mm