Prototyping of Star-Compound Gear Train in Two Types of Rotary Actuators

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Background

The Star Compound Gear Train (SCGT)

- Introduced and discussed in-depth in Bandaru's Thesis
- Key piece in prototyping these Low Complexity Rotary Actuator
- High rated torques possible in a compact size
- Meant for mass-production and low cost, without compromising on performance
- Structurally simple, yet rugged
- Easy to manufactured and assemble
- Only uses spur or helical gears, with an involute tooth profile

Design Through Visual Maps

- Influential output in the main axis, and two critical input parameters in the lower axis
- Every other parameter is held constant
- Figure 4 shows a visual map where:
  - Rated Torque depends on the Gear Mesh Diameter and Gear Train Reduction Ratio
- If solution cannot be found in the map, a designer can quickly either:
  - Change range of the two critical input parameters
  - Or, alter some of the parameters being held constant
- Once map contains multiple design-sets, a designer can juxtapose a plane to mark the minimum requirement of the project
  - After this, based on a project's demand, a designer can pick one or multiple design-sets

Project Goals

The goal of this project is to create prototypes of a Pancake-Type and a Coffee Can-Type Actuator gear train to meet the demands of a modern Multi-Functional Wheelchair (MFW), being developed under Dr. Tesar. The novelty of the actuators comes from the fact that they follow a Star-Compound Gear Trains (SCGT) framework, which allows for a very compact size. With this gearing framework and through design via visual maps, this project seeks to show whether there are benefits of working with this low-complexity, low cost, high-performing actuator.

Furthermore, this project also seeks to show whether through modular design techniques the user can be given multiple design-set options for purchasing.

Fig. 1: MFW Wheel-System

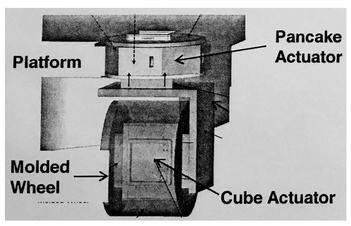

Fig. 2: Multi-Functional Wheelchair (MFW), Maximizes 9 Function for ADL/Work Environments

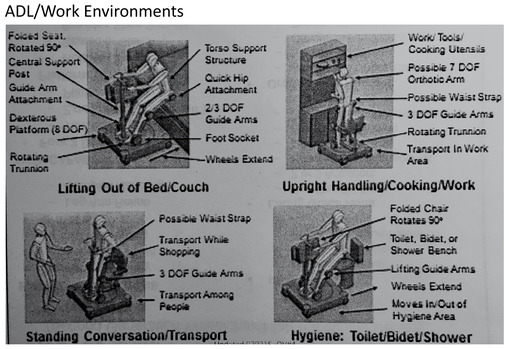

Fig. 3: MFW Showing Linkage

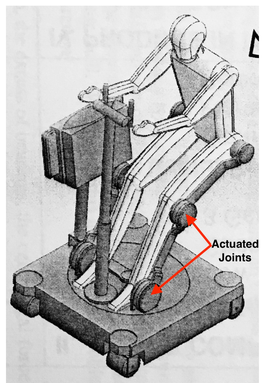

Fig. 4: Coffee Can-Type Actuator

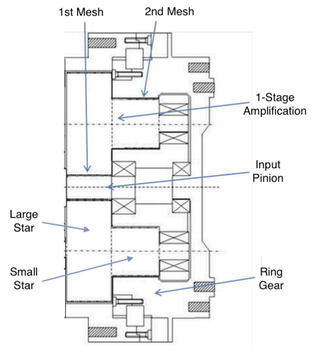

Fig. 5: Pancake-Type Actuator, Generic

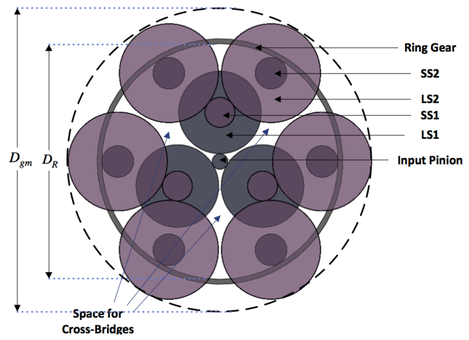

Fig. 4: Coffee Can-Type Actuator, Using Material 1

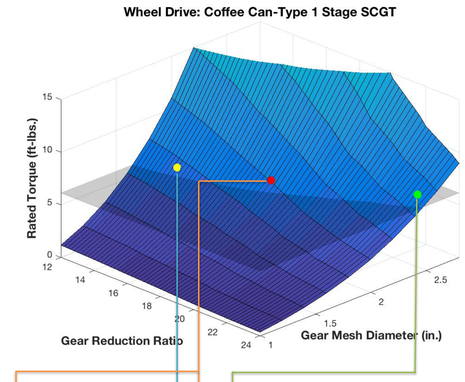

Table 1: Specific Gear Train Result

Ratios	
1st Mesh Gear Reduction	4
2nd Mesh Gear Reduction	4.5
Total Gear Reduction	18
Amplification Gear Ratio	4
Gear Teeth Numbers	
Pinion	11
Large Star	44
Small Star	11
Ring	50
Diameters (inches)	
Gear Mesh	2
Pitch, Pinion	0.20693
Pitch, Large Star	0.82772
Pitch, Small Star	0.29562
Pitch, Internal Ring	1.3303
Helical Angle	15 deg.
Pressure Angle	20 deg.
Rated Torque	6.8 ft-lbf.

Table 2: Multiple Gear Train Results

Material	Torque required (ft.-lbf)	G (gear reduction ratio)	Rated Torque (ft-lbf)	Gear Mesh Diameter (in.)
1	2.04	14	2.19	1.25
	2.04	18	2.19	1.50
	2.04	24	2.04	1.75
	6.13	14	6.46	1.75
	6.13	18	6.8	2
	6.13	24	6.25	2.50
	10.22	14	9.86 - 14.29	2.25
	10.22	18	11.04	2.50
	10.22	24	11.03	3.00
2	2.04	14	2.7	1
	2.04	18	3.8	1.25
	2.04	24	3.1	1.5
	6.13	14	10.2	1.5
	6.13	18	6.8	1.5
	6.13	24	7.8	2
	10.22	14	10.2	1.5
	10.22	18	11.1	1.75
	10.22	24	11.2	2.25
3	2.04	14	3.7	1
	2.04	18	2.5	1
	2.04	24	2.3	1.25
	6.13	14	7.7	1.25
	6.13	18	9.2	1.5
	6.13	24	6.9	1.75
	10.22	14	13.9	1.5
	10.22	18	15.1	1.75
	10.22	24	10.6	2

Acknowledgement & References

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Methodology

In this MFW, each wheel is its own system and is independently driven. Each wheel-system is comprised of a Pancake-Type actuator, which turns the wheel about an axis normal to the floor, and a Coffee Can-Type actuator, which drives the wheel (Figure 1).

The lifting linkage of the MFW is driven by the Pancake-type actuator at each joint (Figure 3).

The design process for the gearing inside these actuators is described in-depth in Bandaur's Thesis. In this project, that design process, along with some judicious selection of gear parameters is modeled in visual maps (using MATLAB).

Some key points of the methodology for design is as follows (using the Coffee Can Type wheel driver as an example):

- Set gear materials to be considered

Molded Steel Gear Material Being Considered

Material	Allowable Bending Stress (Sat) psi	Allowable Pitting Stress (Sac) psi
1	11,000	85,000
2	27,500	95,000
3	37,500	137,500

- Define some scenarios that the system will be used in

Usage Scenarios for Coffee Can-Type Actuator (drives wheel)

Output Torque Requirement (ft-lbf.)	Acceleration	Time (to travel 18.75 ft.)
2.04	0.05 g	9 sec.
6.13	0.15 g	5.2 sec
10.22	0.25 g	4 sec
This system has the following criteria: - Wheel Radius: 5 in. - Weight of System, with user: 300 lbs. - System moving in a ***straight-line*** (distance: 18.75 ft.)		

- Run simulation in MATLAB and get maps (Figure 4) showing possible designs

Results

- From the map (Figure 4), the designer is faced with many options. Table 3 shows a few options for the different materials, exploring only gear ratios of 14, 18, and 24, and meeting the requirements set above.
- Note that these are only a few solutions, many more can be found.
- This table and map shows that the design requirements can be met, but most importantly, it shows that they can be met with low cost gears (Material 1).
- Furthermore, at every point in the map we can get preliminary assembly information, as shown in Table 1 (constraints can be added to get off-the-shelf gear values).
- In the overall project, solutions were found at small gear mesh diameters for the wheel-system. The linkage Pancake-Type actuator needed more premium gears, and even then the gear mesh diameter was too large to be considered. This actuator will need to be reconsidered.

Discussion

Designing through visual maps gives the advantage of seeming multiple results at once. This method relies on a designer's intuition, and it allows a designer to give the user multiple options. These options, as we saw, can be based on quality of materials, reduction of gearing, actuator size, and capable Torque demands.

It is not shown here, but one of the most important parameters that is coming out of this study is the sizing of the actuator (including casing, bearings, shafts, etc.) and the Torque Density of the actuator. These values are what will validate advancement of this project, and a medical device company in Austin, TX is showing great interest in pursuing this with the lab.