Autonomous Steering Mechanism

Main Report

Client: UTS Motorsports

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*Detailed process documentation, including ideation, morphological table and scoring matrix to determine possible designs. This would be justified by calculations and drawings encapsulated in a report.*

# Introduction

The project involves designing a mechatronic system which enables the steering mechanism on the 2022-2023 UTS Motorsports FSAE car to be controlled autonomously. The steering system consists of a steering wheel, universal joint linkages and a steering column into a worm drive steering rack.

The engineer must consider ergonomic constraints as the vehicle must be both manually and autonomously operated. Further, competition regulations must be kept in mind throughout the design process so the final solution can form part of a fully rules-compliant competition car.

Successful completion of this project allows this year’s team to migrate to the newer 2022/23 chassis and progress towards our goal of having a rules compliant autonomous Formula SAE car. The stakeholders involved include UTS Motorsports, UTS and team sponsors.

The proposed design composes of a BLDC mounted on a bracket onto the floor of the car, which is accompanied by a wedge which would help orient the motor to be parallel to the steering column. The motor is then connected via a series of gears and pulleys.

# Project Documentation

The project scope includes the following design documentation:

* Timeline
* Ideation
* Morphological Table
* Scoring Matrix

## Timeline

Below is a flow chart of the process we followed to achieve the final design.

A diagram of a process

Description automatically generated

Figure 1: Timeline Flowchart

## Problem Statement

Design an electromechanical control system capable of rotating the steering column of the UTSMA autonomous car, ensuring it fits safely and ergonomically within the footwell while complying with the FSAE competition regulations.

## Ideation & Morphological Table

Ideating followed the basic principles of discussing how the product could be broken down into sub-assemblies which can be solved individually. These segments include:

### Motor type

This was mainly condensed to two options: A BLDC or a Stepper. Finally, a BLDC Motor was selected: AK80-9.

### Coupling Position

Positioned at the bottom of the steering column to make full use of space constraints with Cockpit Template (Refer to FSAE rules).

### Motor to Steering Coupling

Belt and Pulley drive

### Disengagement

Since the selected motor is backdrivable, the system can be electrically disengaged. Therefore, the considered idea of a mechanical disengage was discarded.

A screenshot of a computer

Description automatically generated

Figure 2: Morphological Table

## Scoring Matrix

Suitable and relevant components were selected from each of the morphological table categories and made into defined “designs”. This would be rated by the following criteria:

### Performance

Delivering the calculated amount of torque without any compromise to the motor.

### Precision & Accuracy

The ability of the steering system to precisely follow the desired path and make accurate adjustments.

### Reliability & Durability

The system’s ability to consistently perform under various operating conditions and resist wear and tear.

### Complexity & Integration

How easy the system is to design, implement, and integrate with the rest of the vehicle, including sensors, controllers, and other hardware.

### Cost-Effectiveness

The overall cost of the steering system, including the cost of components, manufacturing, and maintenance.

### Maintainability

The ease with which the system can be repaired, upgraded, or serviced.

### Safety

Built-in safety features, fail-safes, and redundancy to prevent system failures from compromising the vehicle’s performance.

### Modularity

Ease of create a modular variant, that is compliant with FSAE rules.

### Scalability & Flexibility

Ease of using current design to be used in future iterations.

Using these criteria, the following design was proposed:

BLDC controlled using a magnetic rotary encoder (being positioned directly at the end of the motor shaft). It would be situated in the floor, driven by a set of gears and pulleys. The system can be disengaged by electrically disconnecting the motor, as it is backdrivable. This is shown in the figure below.

However, with a slight change in motors led to the sensor being discarded.

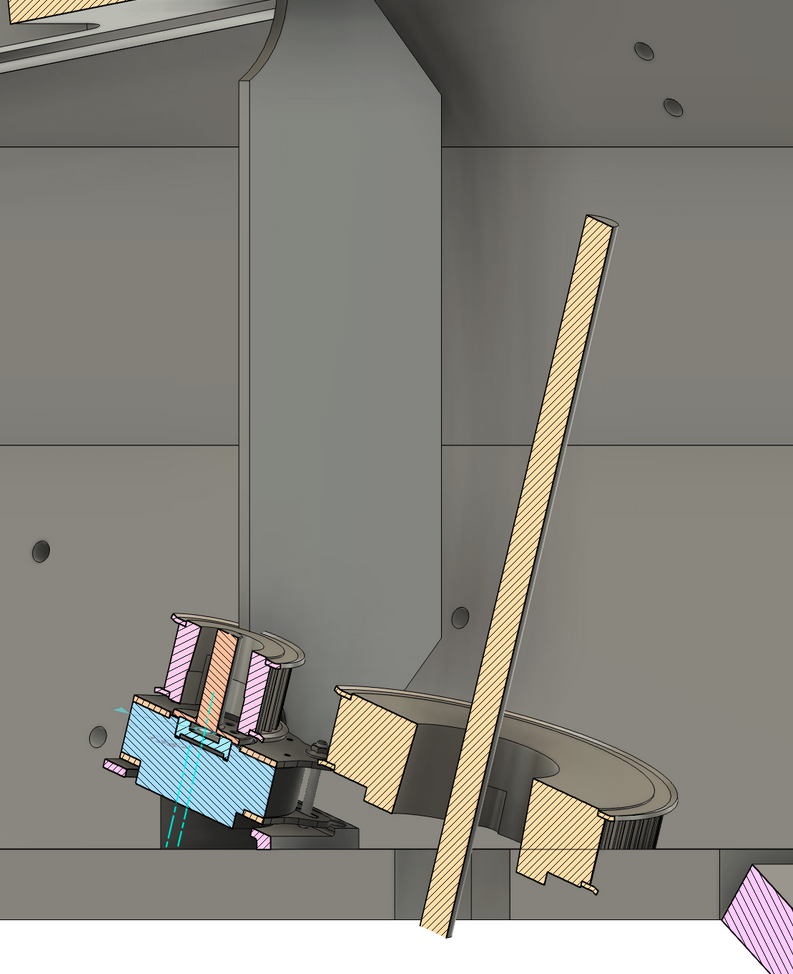


Figure 3: Mechanism fitted in Car Cockpit

# Issues & Feedback

* Motor torque calculations took a long time to confirm and validate, resulting in the team being able to purchase component (which has to be verified with tutor using calculations and confirmation from UTSMS) a couple of weeks in.
* Communications were not consistent in the first few weeks, which unfortunately was not completely resolved even by the end of the project.
* Issues with team members not showing up to meetings and not living up to agreements on time.
* Issues with final design not being in accordance with space constraints (refer to CAD and FSAE rules).
* Difficulty to come to decisions about final design.

# Design

## Pulley/Belt Design

This section covers the complete (for the most part) design for the belt and pulley system for the autonomous steering system.

### Determine Shaft diameters

**From CAD model:**

* Steering shaft column outer diameter: 15mm
* Steering shaft column inner diameter: 10mm

However, on the existing 2022 UTS Motorsports Electric car physical shaft, it is a solid 15mm steering column shaft.

Figure  
CAD model close-up of shaft

A blue circle with arrows and lines

Description automatically generated

(Source: UTS Electric Motorsports, 2023)

Figure   
Drawing of ’22 steering column

A close-up of a blueprint

Description automatically generated  
(Source: UTS Electric Motorsports, 2023)

**From manual calculations and computer simulations:**

Due to the lack of documentation, particularly with the design or the current steering system, step-by-step hand calculations were performed to analyse whether or not the current thickness of 15mm shaft diameter can support the motor’s torque. Please refer to “Analysis of Column Shaft” documentation.  
Computer simulations in terms of finite element analysis (FEA) was performed to verify our hand calculations.

**Motor shaft diameter:**

The motor shaft of the AK1-9 motor will be customised to suit the mounting on the motor hub. The diameter of the shaft will be determined by both torsion, radial forces, along with axial forces.

Figure  
Picture of AK10-9 V2.0

A black circular object with white text

Description automatically generated  
(Source: Tmotor, n.d)

**Manual calculations and computer simulations:**

Both hand calculations and FEA were performed on the design of the motor shaft. Please refer to “Analysis of Column Shaft” documentation.

### Belt Selection

There are several types of pulley belts available such as flat, V, Wedge, Synchronous belts along with other types.

Table  
Comparison of Belt performance

A table with numbers and text

Description automatically generated

(Source: Childs, Peter R.N.. (2014). Mechanical Design Engineering Handbook. Elsevier)

Figure  
Various Belt Cross Sections

A diagram of different types of belt

Description automatically generated

(Various Belts - Source: Childs, Peter R.N.. (2014). Mechanical Design Engineering Handbook. Elsevier)

Referring to the Table 12.1, synchronous belts can output an optimum efficiency of up to 98%, due to their teeth engagement between the belt teeth and the grooves of the pulley. Due to the required precise motion control of an autonomous steering system, a slippage between the belt and the pulley is highly not preferred, which the synchronous belt as the name suggests provides exact shaft synchronization (with the exception of belt creep).  
Synchronous belts need significantly lower installation tension compared to V-belts, which results in reduced stress on drive components like shafts and bearings. Hence, along with the Figure 12.4, synchronous belt has been selected.

A diagram of a speed limit

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### General Selection Procedure – Synchronous belt pulley system

#### Define the rotational speeds of the motor shafts.

Rated motor (AK10-9 V2) speed:

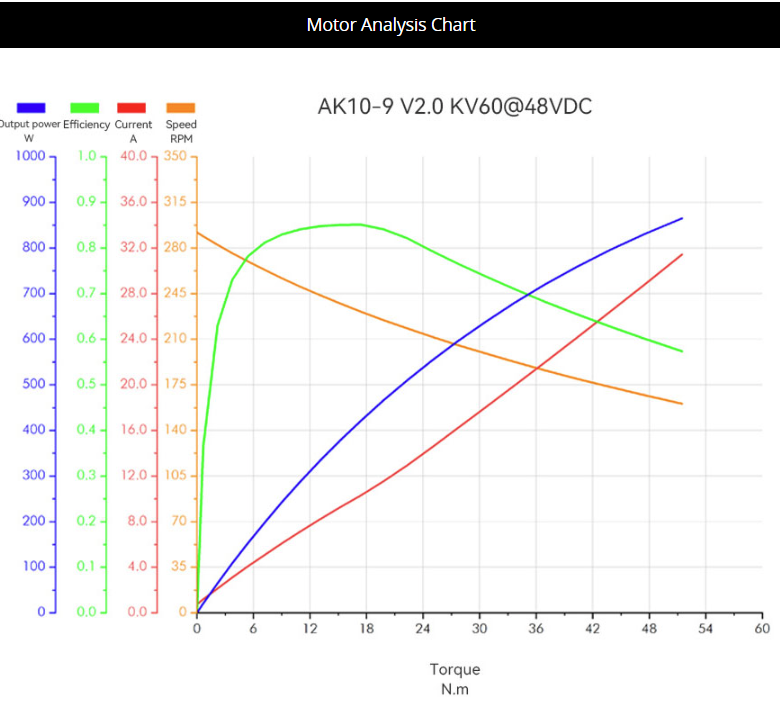
- 228 rpm at 18nm (rated torque)

24.9N Steering force (With Factor of Safety of 1.5 from 16.6N steering force):  
- ~200 rpm at 25nm

Motor Analysis Chart:

### Pulley selection

Table  
Motor Analysis Chart

  
(Source: Tmotor, n.d)

N.m to hp:

For 18nm:

= 0.576HP

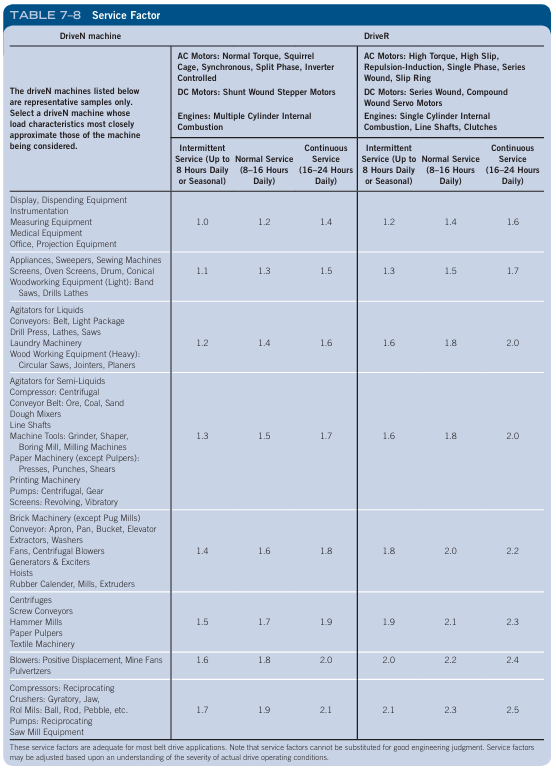
For 25nm:

= 0.702 HP

### Determine the service factor.

Using Table 7-8 below, using good engineering judgement, a service factor of 1.2 has been selected.

Table  
Synchronous Belt Service Factor Table

  
(Source: Mott, Robert L, 2018)

### Calculate the design power.

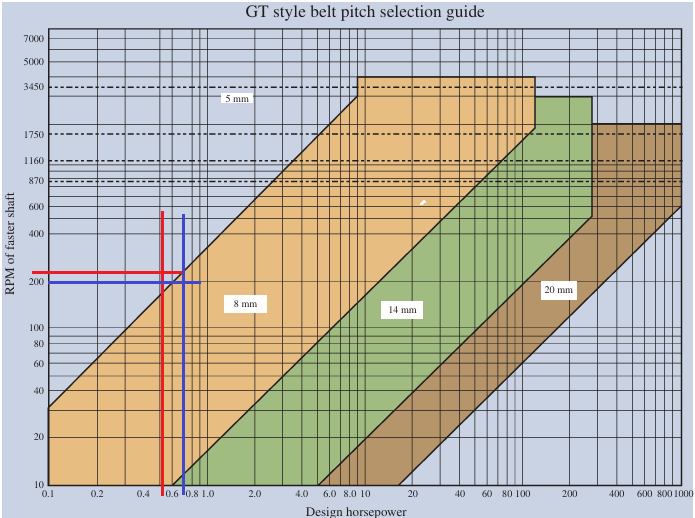
****

Using the formula above;

- the design rated power is = 0.576HP x 1.2 = 0.691 HP (0.691 x 0.7457 = 0.52 kW)  
- the design peak power is = 0.702 HP x 1.2 = 0.8424 HP (0.8424 x 0.7457 = 0.63kW)

1. **Determine required pitch of the belt.**

Graph  
GT Belt Selection Guide

(Source: Mott, Robert L, 2018)

Using the table above, the red lines depict the selection for the rated torque, whilst the blue lines indicate the use of peak torque. Since the majority of the imaginary curve from the red line intersection to the blue line intersection, a 5mm belt pitch would be considered a reasonable design choice. However, 8mm had to be chosen due to belt selection requirements.

1. **Determine the velocity ratio VR belt between the driver and driven sprockets.**

A math formula with black text

Description automatically generated with medium confidence

To determine the sizes/ratio of the driven and driver pulleys, giving the following:

Motor operational torque: 18nm  
Required torque: 24.9nm

An adequate pulley size ratio is needed to meet the steering force requirement of 24.9nm.

As the torque ratio is directly related to the velocity ratio:

Torque ratio =

Using the values of 24.9nm of steering torque (with FOS 1.5), with 24.9nm of required torque,

**Torque ratio = ≈ 1**

Therefore the driven pulley (on steering column shaft) must be **1** or more greater than the driver pulley (on the motor).

When the car is in motion, using a dynamic torque of 27nm (from 13.5N x FOS 2), At moderate dynamic or during sudden spikes:

Motor rated torque: 18nm  
Required torque: 27nm

**Torque ratio = ≈ 1.5**

Thus, the driven pulley (attached to the steering column shaft) needs to be at least 1.38 times larger than the driver pulley (connected to the motor).

**8mm Pitch Belt:**

Table  
Screenshot of 8mm Synchronous Belt Drive Table Part 1

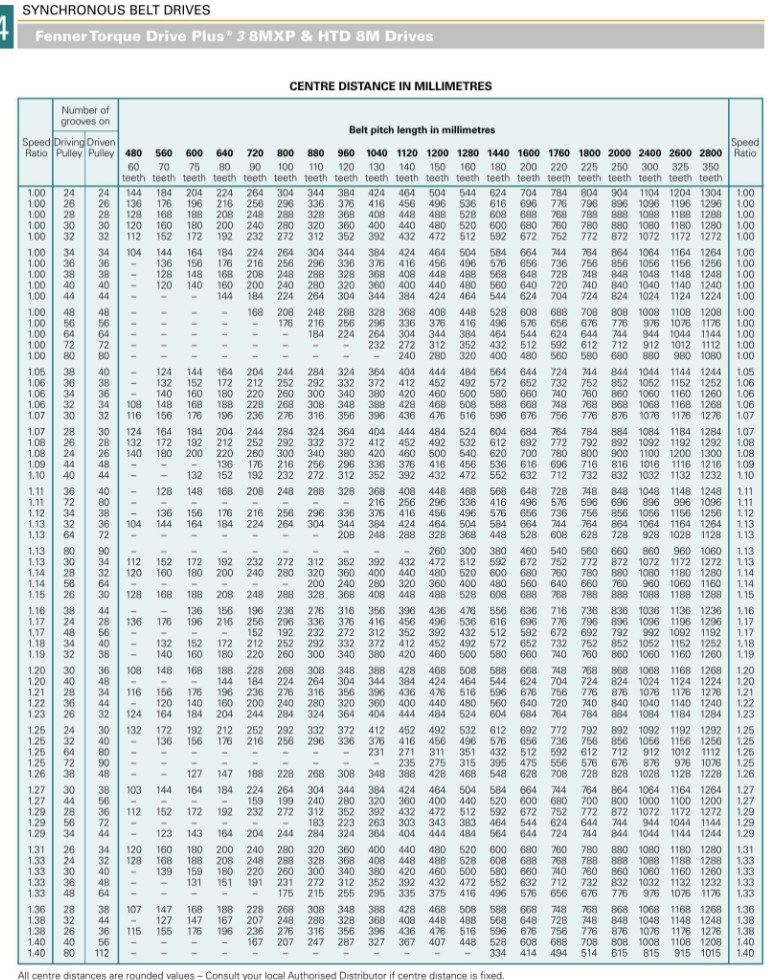
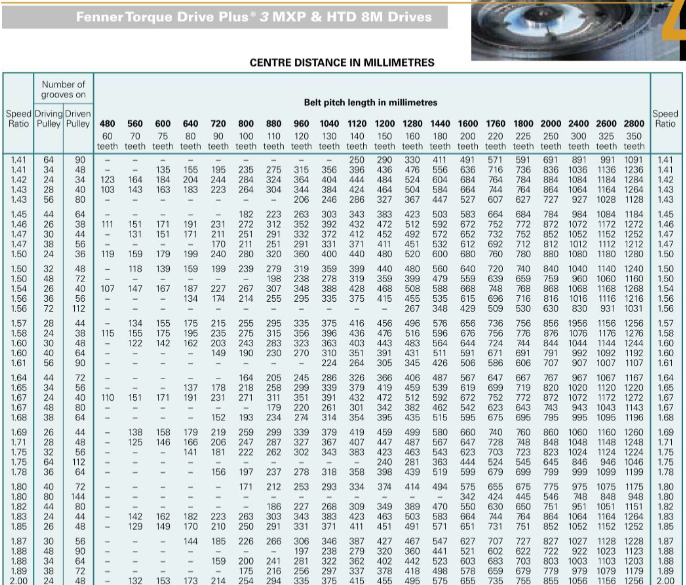
****(Source: Fenner, 2006)

Table  
Screenshot of 8mm Synchronous Belt Drive Table Part 2

****(Source: Fenner. 2006)