**Module Title: Connected and Autonomous Vehicles Systems** 

**School of Mechanical Engineering** **May/June 2023**

**Calculator instructions:**

- You are allowed to use a non-programmable calculator in this exam.

**Dictionary instructions:**

- You are not allowed to use your own dictionary in this examination. A basic English dictionary is available to use. Raise your hand and ask an invigilator if you need it.

**Exam information:**

- There are 6 pages to this exam.
- There will be 2 hours to complete this exam.
- There are 4 questions and each is worth **25** marks.
- **Answer all questions**.
- A formula sheet is provided at the end of the exam paper.
- This assessment is worth **50%** of the overall module mark.
- If you think that any additional data is required, make a reasonable assumption and indicate it clearly in your answer.

**Please do not remove this paper from the exam venue.**

**Q1.**

The transition from driver-operated to connected autonomous vehicles has been enabled by the gradual development of automation technology leading to fully autonomous vehicle operation.

a) The Society of Automotive Engineers (SAE) defines levels of driving automation. How many levels have been defined? How many of them require humans to monitor the environment and control the vehicle, and how many levels require automation to monitor the environment and control the vehicle?

**[6 marks]**

b) Describe the main differences between levels of autonomy 3 and 4.

**[6 marks]**

c) How many sensors are required to achieve level 4 autonomy? List them in order of priority.

**[6 marks]**

d) Which sensors are required to create autonomous lane keeping function. Describe the main steps of the lane-keeping algorithm.

**[7 marks]**

**Q2.**

To provide good environment recognition Light Detection and Ranging (LIDAR), camera and ultrasound sensors can be used.

a) Describe the principle of operation of the stereoscopic camera.

**[5 marks]**

b) The LIDAR sensor operation can be characterised by a number of operating parameters related to the output and input signals. These signals can be affected by environmental conditions. List the main operating parameters of the LIDAR sensor that can be affected by the rain and explain how they are affected.

**[5 marks]**

c) A LIDAR sensor has a field of view of 360 degrees horizontally and 40 degrees vertically, and its angular resolution is 0.4 degrees. The maximum frame rate is 20 Hz. Calculate how many points can be updated per second.

**[5 marks]**

d) Data points obtained from the LIDAR sensor will be processed by the on-board computer with a single processor; each data point will take 350 processor cycles (ticks) to process, and other functions will take another 800,000 cycles, what should be the minimum processor speed in MHz.

**[5 marks]**

e) Calculate the theoretical maximum signal update frequency of the ultrasound sensor with a range of 10 m, assuming the speed of sound to be $c_s$=343 m/s. Under what circumstances the update frequency can be increased.

**[5 marks]**

**Q3.**

A prototype of an autonomous vehicle is to be fitted with a new steering system based on a hydraulic actuator that is presented in Figures Q3a and Q3b. Calculate the main parameters described below for this steering system for a vehicle with a weight of 1000 kg on the steering axle and 205/55R16 tyres. Assume a ratio of E/B=0.4, circular shape of the tyre patch, and a wheel steering angle of +/-35º. Use an arm radius equal to the radius of the wheel.

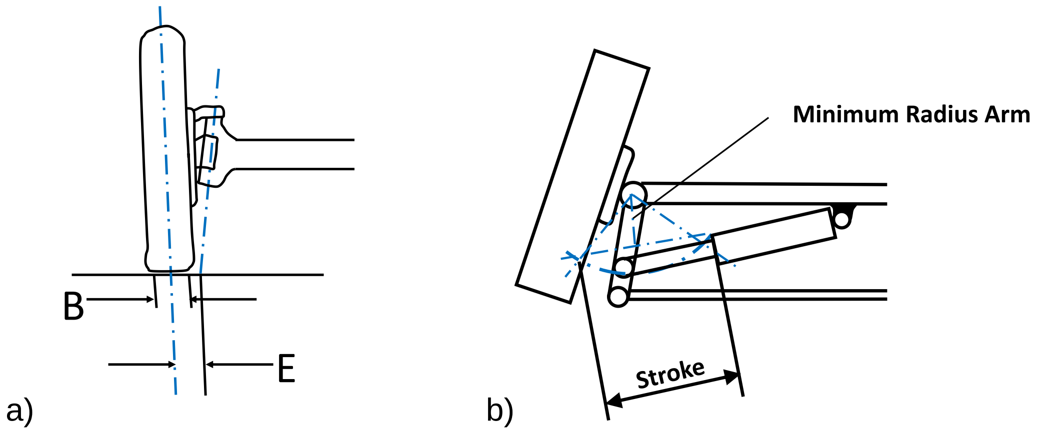


**Figure Q3** a) Kingpin offset and tyre patch width, b) Configuration of hydraulic actuator.

Calculate:

a) Calculate the kingpin torque ($T_K$) assuming the coefficient of friction μ=0.32.

**[5 marks]**

b) Determine the minimum cylinder force ($F_C$) necessary to turn the wheel when the vehicle is stationary.

**[5 marks]**

c) Calculate the minimum cylinder area ($A_C$) if the hydraulic pump can deliver a pressure of 4 MPa.

**[5 marks]**

d) Determine the cylinder stroke (S) needed to achieve the steering angle of +/-35º

**[5 marks]**

e) Calculate the swept volume of hydraulic oil needed to turn wheels from -35º to +35º

**[5 marks]**

**Q4.**

The legal requirement for autonomous vehicles that are currently under development will require several steps to allow a vehicle to operate in autonomous mode. Please describe the following steps of the legal framework:

a) Authorisation: what is the main purpose of authorisation, and who will have to obtain the authorisation, what type of requirements will the vehicle have to adhere to in order to obtain it.

**[5 marks]**

b) Operator licensing: what is the operator license and who will need it.

**[5 marks]**

c) Incident investigation: when and why they should be carried out, what would be the main purpose, and how the outcomes can be used.

**[5 marks]**

d) Insurance procedures: how the responsibility for any issues with the vehicle that may cause an accident, will be shared between involved parties.

**[5 marks]**

e) Cybersecurity and data: Describe the main security vulnerabilities that may compromise the connected and autonomous vehicle systems.

**[5 marks]**

## Formulae sheet

This formulae sheet contains the most commonly used formulae encountered within the MECH5170 module. The equations are grouped under the main section headings associated with the delivery of the module. You may assume that all symbols have their usual meaning.

### General:

$P = TE\ V$ $\quad P = T\omega$ $\quad A = \frac{\pi d^2}{4}$ $\quad I_x = I_y = \frac{\pi d^4}{64}$ $\quad J = \frac{\pi d^4}{32}$

$D = \frac{1}{2} C_d A \rho V^2$ $\quad R_R = mg\ C_r$ $\quad R_s = 2mg\ C_r$ $\quad G_R = mg\ sin\theta$ $\quad 1mile = 1609m$ $\quad 1\ in\ 3\ slope = 18.4°$

### Transmission:

$\Sigma Fx = TE - Rr - Gr - D = 0$ $\quad TE = \frac{Te\,(n_g \cdot n_f)(\eta_g \cdot \eta_f)}{r}$ $\quad TE = \frac{T_w}{r} = \mu N$ $\quad T_w = T_e\,(n_g \cdot n_f)(\eta_g \cdot \eta_f)$

$N_w = \frac{60 \cdot V}{2 \cdot \pi \cdot r}$ $\quad N_w = \frac{Ne}{n_g \cdot n_f}$ $\quad V = 2\pi r\,\frac{N_w}{60}$ $\quad R = \sqrt[(i-1)]{\frac{n1}{n_i}}$ $\quad n_i = n_{i+1} \cdot R$ $\quad m_{eq} = \frac{I_{eq}}{r^2} = \frac{I_w + I_d\,n_f^2 + I_g\,n_g^2\,n_f^2}{r^2}$

### Batteries:

Indexes: c - cell, s - string, b - battery, p - pack, r - range

$U = I \cdot R$ [V] $\quad E = I \cdot U$ [Wh] $\quad C = I \cdot t$ [Ah]

$E_{bs} = E_{bc} \cdot N_{cs}$ [Wh] $\quad E_{bp} = U_{bp} \cdot C_r$ [Wh] $\quad E_{bc} = U_{bc} \cdot C_{bc}$ [Wh]

$N_{cs} = \frac{U_{bp}}{U_{bc}}$ $\quad N_s = \frac{E_{bp}}{E_{bs}}$ $\quad N_c = N_s \cdot N_{cs}$

### By-wire steering system:

Kingpin torque $T_k = W \times \mu \times \sqrt{\frac{B^2}{8} + E^2}$ $\quad W = m \cdot g$

Cylinder force $F_C = \frac{T_K}{R_{\min}}$

Cylinder surface area $A_c = \frac{F_c}{P}$

Swept volume $V_s = \frac{\pi \times D_B^2}{4} \times S$

### LIDAR, Ultrasound sensors:

$d_L = \frac{t \cdot c_L}{2}$ $\quad d_{US} = \frac{t \cdot c_s}{2}$ $\quad f = \frac{1}{t}$

### CPU

1MHz = 1 000 000 cycles (ticks) / second