

Project report
Project 1 – TSFS09

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This report template includes project 1 in the course Modeling and Control of Engines and Drivelines (TSFS09). The purpose of this template is to assist you as you will present your findings and conclusions. It can be difficult to know how detailed the report should be, therefore some examples are included in this template.

Another major point of this template is that you will have everything at place. It will become easier for us to inform you and help you if you get stuck, but most of all it helps yourselves. What you write in Chapter 2 and what you do in preparatory tasks, is that you will build the rest of the work on. Just remember to bring your report and look at it when you are working on the project!

The template already contains a lot of text. Anything which is written in normal font is text that you can leave to remain. Text written in italics like this, you shall delete as it is only meant to be helpful to you while you write the report.

If you want to write in another word processing tool that is obviously fine, but the different sections and subsections must be well separated and easy to find.

You can choose to write your report in Swedish or English.

There are many constant parameters which are required in the models, it is your task to differentiate between the ones that need to be obtained from the measurements and those which relate to e.g. gas properties.

NOTE: *In addition to the measurements required in Project 1, we also need to perform measurements for Project 2. These measurements are added with brief explanatory text in sections 2.10, and 2.11 below, and performed here to avoid duplicate measurement occasions. The star (★) before the section name indicates that these measurements are for Project 2. The projects 2 measurements are included in projects 1 report **only the experiment plans** (so you know what to measure and how), and thus not the implementation and validation of the models estimated from these measurements. **Implementation and Validation for these components should instead be reported in project report for Project 2.***

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Chapter 1

Introduction

This project report deals primarily with a turbocharged engine. A mathematical model for the engine is to be developed and implemented, its model parameters identified from measured data, and the various models are validated. A controller is connected to the fuel injection system, which uses both feedforward and feedback from the discrete lambda sensor. Finally, the engine is coupled with a number of ready-made modules containing driver, clutch and driveline models. This is in order to perform simulations of the complete vehicle. A series of experiments are conducted with the aim to study the emission formation and consumption. The tool that is used for implementation is Matlab combined with Simulink.

Besides working on the engine model, the report addresses a series of studies, whose purpose is to illustrate how the energy stored in fuel is converted into a driving torque during the engine operating cycle, and the losses that may occur.

- Throttle
- Intake manifold
- Fuel injector
- Cylinder
- Exhaust system with lambda sensor
- ★ Compressors wheel diameter (used in project 2)
- ★ Wastegate time constant (used in project 2)

Because the simulations should be done with both warm and cold engine, it is also explored how long it takes for the catalyst to become warm. Sensors that measure air mass flow and pressure in the intake manifold are assumed to have negligible dynamics, while only the delays at lambda measurement are taken into account and exhaust gas mixing dynamics in the exhaust manifold are neglected. The control signals which are the inputs to the engine model are:

- Accelerator pedal position (β_{ped}),
- Engine speed (N),
- Fuel injection time (t_{inj}),
- Wastegate control signal (PWM_{wg}).

The control signals that are going to be mentioned in the experiment plans, must be selected only among these. During measurements in the lab, control signals are the ones which can be controlled from the control room.

The entire engine model block in Simulink should produce the following output signals

- Engine torque (M_e),
- λ measured by the discrete sensor ($\lambda_{\text{bc, disc}}$),
- Air mass flow past the throttle (\dot{m}_{at})
- Intake manifold pressure (p_{im}).
- Exhaust manifold pressure (p_{em}).

For your convenience, a complete model description and experimental plan for the accelerator pedal, and most of model description for the throttle are already included in the report template. Use this as a template when you write model description and experimental plan for other components. You should have replaced every ??? in this template before submitting your report.

2.1 Accelerator pedal

2.1.1 Model description

Model input signal(s): Accelerator pedal position (β_{ped}),

Model output signal(s): Throttle angle (α_{th})

Model: The throttle angle is calculated by the following differential equation:

$$\dot{\alpha}_{\text{th}} = \frac{1}{\tau_{\text{th}}}(\beta_{\text{ped}} - \alpha_{\text{th}}) \quad (2.1)$$

where β_{ped} and α_{th} can change continuously between 0 and 1.

Parameter to find (via measurement): Time constant of the throttle (τ_{th}).

Other parameters in the model: -

2.1.2 Experiment plan

Signal(s) to be measured: Throttle angle (α_{th})

Control signal(s): Accelerator pedal position (β_{ped})

Type of experiment: Dynamic.

Measurement description: While engine runs with a constant speed at an operating point many steps (up-down-up-down-...) are performed in accelerator pedal position. The times between steps are selected such that measured signals become stable before the next step is done.

How to find the parameter(s): Since it is assumed that the system has first order dynamics, the step response expressed in time domain is:

$$\alpha_{\text{th}}(t) = \left(1 - e^{-\frac{t-t_0}{\tau_{\text{th}}}}\right) (\beta_{\text{ped,new}} - \beta_{\text{ped,old}}) + \beta_{\text{ped,old}} \quad (2.2)$$

where t_0 is the time point when the step happens. At time $t = \tau_{\text{th}} + t_0$ is

$$\left(1 - e^{-\frac{t-t_0}{\tau_{\text{th}}}}\right) = 1 - e^{-1} \approx 0.63 \quad (2.3)$$

Therefore the time constant is determined as the time interval between the instance when the first change in the signal is observed until throttle angle reaches 63% of its final values.

2.2 Throttle

The air mass flow past the throttle depends on throttle angle and ambient pressures and temperatures. In most of the engine operating points it is a significant pressure drop across the throttle which is well described by compressible flow models.

$$\dot{m}_{\text{at}} = \frac{p_{\text{us}}}{\sqrt{RT_{\text{us}}}} A_{\text{eff}}(\alpha_{\text{th}}) \Psi(\Pi), \quad \Pi = \frac{p_{\text{ds}}}{p_{\text{us}}}$$

which is also found in the textbook along with the expression for $\Psi(\Pi)$. The only thing that is unknown is how the effective area A_{eff} depends on throttle plate angle α_{th} . Here we use ...

Several models are proposed in the textbook, here a quadratic polynomial in α_{th} is recommended.

2.2.1 Model description

Model input signal(s): Throttle angle (α_{th}), Pressure before throttle ($p_{\text{bef,thr}}$), Pressure after throttle (is equal to Intake manifold pressure p_{im}).

Model output signal(s): Air mass flow rate (\dot{m}_{at})

Model: Air mass flow rate past the throttle is given by:

$$\dot{m}_{\text{at}} = \frac{p_{\text{bef,thr}}}{\sqrt{RT_{\text{bef,thr}}}} A_{\text{eff}}(\alpha_{\text{th}}) \Psi(\Pi), \quad \Pi = \frac{p_{\text{im}}}{p_{\text{bef,thr}}} \quad (2.4)$$

$$A_{\text{eff}}(\alpha_{\text{th}}) = \text{????} \quad (2.5)$$

$$\Psi = \sqrt{\frac{2\gamma}{\gamma-1} \left(\Pi_{\text{lim}}^{\frac{2}{\gamma}} - \Pi_{\text{lim}}^{\frac{\gamma+1}{\gamma}} \right)}, \quad \Pi_{\text{lim}} = \max \left(\Pi, \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma}{\gamma-1}} \right) \quad (2.6)$$

Parameter to find: Parameters ???? in the effective area (A_{eff}) model, temperature before throttle ($T_{\text{bef,thr}}$).

Other parameters in the model: Gas constant (R) and ratio between specific heat capacities, $\gamma = c_p/c_v$.

2.2.2 Experiment plan

Signal(s) to be measured: Throttle angle (α_{th}), Air mass flow (\dot{m}_{at}), Intake manifold pressure (p_{im}), Pressure before throttle ($p_{\text{bef,thr}}$)

Control signal(s): Accelerator pedal position (β_{ped})

Type of experiment: ????

Measurement description: ????

How to find parameters: Since it is important that the model is well suited ?? when there is a significant pressure drop across the throttle plate only ?? points with $\Pi < 0.73$ are used in the parameter estimation. ????

2.3 Intake manifold

Pressure dynamics in intake manifold. ??????????????????????

2.3.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.3.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.4 Fuel injector

????????????????????

2.4.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.4.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.5 Cylinder

In the cylinder model there is one sub-model for the generated torque, one sub-model for the engine temperature and another one for the air/fuel ratio inside the cylinder (λ_{cyl}).

tips: Equation 7.55 in the book is recommended for torque modeling, read chapter 7.9.[1,2,3] before doing this part. For friction modeling use the Heywood model on page 191 but you have to find the model constants. For the temperature model, read the project compendium.

2.5.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.5.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.6 Exhaust manifold

????????????????????

2.6.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.6.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.7 Exhaust flow

????????????????????

2.7.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.7.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.8 Lambda sensor

models for continuous and discrete lambda sensors, before catalyst are required.

2.8.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: τ_{dbc}, τ_λ

Other parameters in the model:

2.8.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameter(s): ????

2.9 Catalyst light-off

????????????????????

2.9.1 Model description

Model input signal(s): ????

Model output signal(s): ????

Model: ????

Parameter to find: ????

Other parameters in the model: ????

2.9.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.10 ★ Compressor- and turbine impeller diameters

As part of the compressor model for Project 2, the outer wheel diameter of compressor impeller (d_{C2}) is needed. This can most easily be measured by using calipers. In the same way, the turbine inlet diameter (d_{T1}) should be measured with calipers.

Parameter to find: Outer diameter of compressor wheel d_{C2} and outer diameter of turbine wheel d_{T1} .

2.11 ★ Wastegate

Wastegate position of a turbocharged engine is normally controlled by the pressure on one side of a membrane. Pressure on other side of the membrane is normal ambient pressure. The pressure is controlled by using a mixing valve, where two sources with different pressure alternately are connected to the pressure chamber of the wastegate. This mixing valve is controlled by a PWM signal. An overview of the various components included in the wastegate controller on the turbocharged engine lab is shown in Figure 2.2.

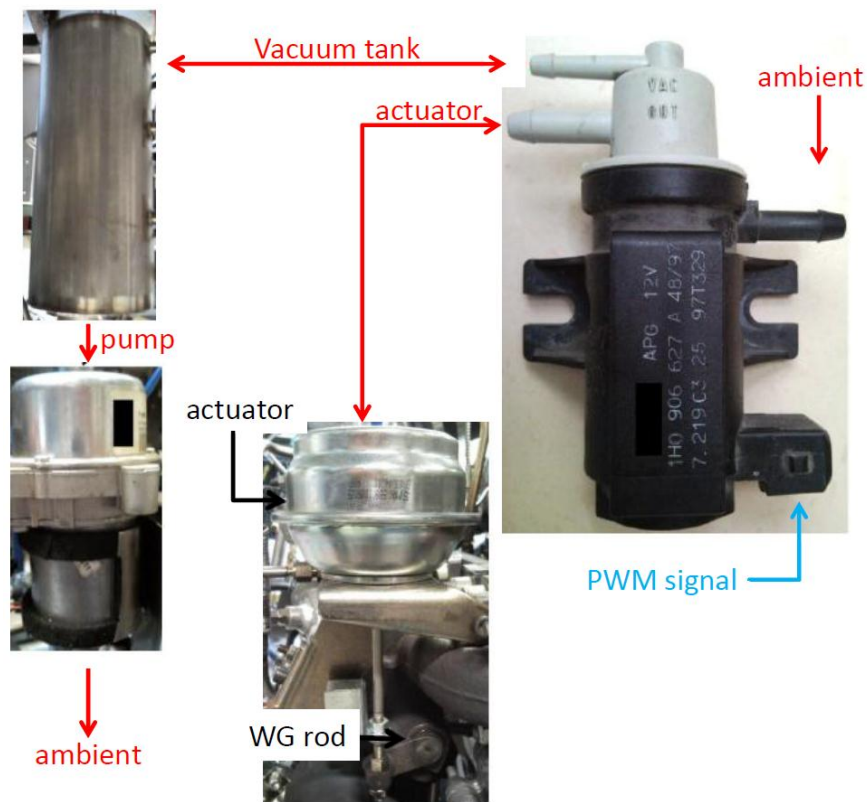


Figure 2.2: Snapshot of the wastegate actuation system. A PWM signal controls the pressure in an actuator chamber, by alternately (and quickly), connecting the chamber to two different pressure sources. The pressure in actuator chamber then actuates a membrane that controls actuation lever. A return spring also serves on the actuator chamber which is why a greater pressure difference between the membrane different sides is required for larger change in position of the arm.

The PWM signal alternates between +5 V and ground, and the relative length difference between the +5 V level and ground-level controls the valve behavior. The frequency of the PWM signal is so high that an almost continuous signal is obtained (ie change between +5 V and ground occurs with the order

of hundred Hz, because wastegate system frequency is significantly lower). The position of the wastegate arm can be measured in lab, and the PWM signal to the mixing valve can be controlled if wanted. A first order behavior, as for throttle angle, is assumed here. Model description and experiment plan for the wastegate will therefore largely follow the accelerator pedal.

2.11.1 Model description

Model input signal(s): PWM signal for wastegate valve (PWM_{wg})

Model output signal(s): Position of the wastegate (pos_{wg})

Model: Similar to the accelerator pedal model the wastegate position can be calculated by ????

Parameter to find: τ_{wg}

Other parameters in the model: ????

2.11.2 Experiment plan

Signal(s) to be measured: ????

Control signal(s): ????

Type of experiment: ????

Measurement description: ????

How to find parameters: ????

2.12 Complete engine

Now that models are described and input-output-control signals are defined for all components, the block diagram of entire engine model can be illustrated as shown in Figure 2.3.

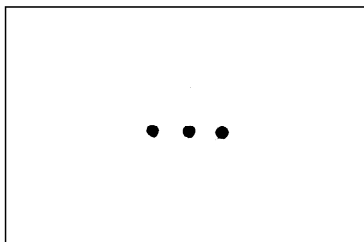


Figure 2.3: Block diagram of complete engine. *Draw a block diagram of the entire engine, in which you can clearly see how the signals (the physical quantities) flow between the various sub-blocks. Having the block diagram in this figure right will later, in project 1C, help you when implementing the models in Simulink.*

Chapter 3

Stationary analysis and model validation

Project 1B.

The enginemap can be downloaded from:

www.fs.isy.liu.se/Edu/Courses/TSFS09/Projekt1/EngineTests/

This chapter outlines and discusses the results of projects 1B. The aim in projects 1B is to show how engine torque can be produced from chemically stored energy, and where losses can occur. Approach is described by presenting the utilized equations and the name of the used data file(s). The results of parameter estimations in models of different engine components are also reported and the models are validated against measurements.

This chapter will be submitted as the second submission, i.e. after the project 1B has been implemented. Attach the Matlab code.

Preparatory tasks need not be explained in the report, but be aware that they can provide valuable clues as you e.g. explain figures.

3.1 In-cylinder analysis

3.1.1 pv diagram

3.1.2 Otto cycle

3.1.3 Specific fuel consumption

3.2 Model validation

In this section, the models developed in previous chapter are compared against the measurement data.

3.2.1 Accelerator pedal

The accelerator pedal takes pedal position (β_{ped}) as input and provides throttle angle (α_{th}) as output. The model is described by the equation:

$$\dot{\alpha}_{\text{th}} = \frac{1}{\tau_{\text{th}}}(\beta_{\text{ped}} - \alpha_{\text{th}}) \quad (3.1)$$

Parameter(s) value: Time constant for the throttle τ_{th} in (3.1) is estimated to be 0.???? sec.

Measurement file: *throttleStep.mat*.

Method: The time constant is estimated as the time that it takes for the step to reach 63% of the final value as explained in the experiment plan 2.1.2.

Validation: In Figure 3.1 we see that the model fits the measured step response. The rise time certainly depends on how big of a step is made ??but this will not have any significant impact on experiments done in this project.

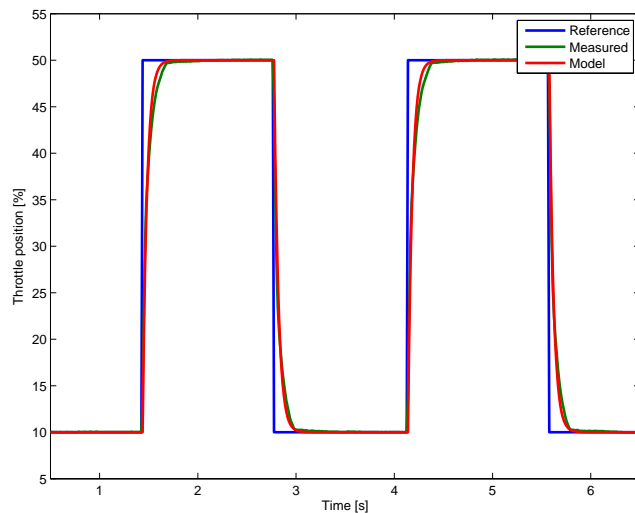


Figure 3.1: Estimation of time constant for throttle. **Note: This will be replaced by a figure from you.**

3.2.2 Throttle

The model of the throttle determines the air mass flow rate into the intake manifold based on throttle angle. Model equation presented in Section 2.2, is repeated here

$$\begin{aligned} \dot{m}_{\text{at}} &= \frac{p_{\text{amb}}}{\sqrt{RT_{\text{amb}}}} A_{\text{eff}}(\alpha_{\text{th}}) \Psi(\Pi), & \Pi &= \frac{p_{\text{im}}}{p_{\text{amb}}} \\ A_{\text{eff}}(\alpha_{\text{th}}) &= \dots \\ \Psi &= \sqrt{\frac{2\gamma}{\gamma-1} \left(\Pi_{\text{lim}}^{\frac{2}{\gamma}} - \Pi_{\text{lim}}^{\frac{\gamma+1}{\gamma}} \right)}, & \Pi_{\text{lim}} &= \max \left(\Pi, \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma}{\gamma-1}} \right) \end{aligned}$$

What needs to be determined is the parameters of the polynomial for the effective area.

Parameter(s) value: ????

Measurement file: ????

Method: For each measurement point the effective throttle area is calculated, then the parameters are adjusted with least squares method to the measured data.

Validation: The model and measurements are compared in Figure ???. The figure shows that the modeled and measured values are in a good agreement in the range ????, but not in ????, range, and ...

3.2.3 Intake manifold

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.4 Fuel injector

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.5 Cylinder

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.6 Exhaust manifold

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.7 Exhaust flow

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.8 Lambda sensor

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.2.9 Catalyst light-off

Parameter(s) value: ????

Measurement file: ????

Method: ????

Validation: ????

3.3 Table of Parameters

After validation of models, all estimated parameters in different sub models must be presented in this table. This makes it easier for us to correct your reports, and for you to reach and find different values during model implementation in Simulink.

All estimated parameters in the different engine sub models are summarized in table 3.1. *Number of empty rows in front of each component is randomly selected and should not be inferred as number of parameters.*

Table 3.1: Estimated parameters in engine sub models

Component	Parameter	Value
Accelerator pedal	τ_{th}	0.??? [sec]
Throttle

Intake manifold

Fuel injector

Cylinder

Exhaust manifold

Exhaust flow

Lambda sensor

Catalyst light-off

Chapter 4

Implementation of engine model

Project 1C.

This chapter presents how different models for sub components of the engine are implemented in Simulink.

4.1 Accelerator pedal

Implementation: In Figure 4.1 the implementation of accelerator pedal model in Simulink is shown.

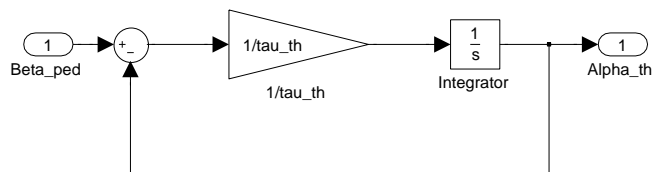


Figure 4.1: Simulink model of the implemented throttle.

4.2 Throttle

Implementation:

4.3 Intake manifold

Implementation:

4.4 Fuel injector

Implementation:

4.5 Cylinder

Implementation:

4.6 Exhaust manifold

Implementation:

4.7 Exhaust flow

Implementation:

4.8 Lambda sensor

Implementation:

4.9 Complete engine model

Implementation: Figure ??? shows the entire engine model implemented in Simulink which is in agreement with the initial design in Figure 2.3.

Chapter 5

Controller

Project 1C, continued.

A fuel controller is connected to the engine fuel injection system. In this chapter, the design of the controller, the way we went about it to determine the controller parameters, and figures showing that we have succeeded are presented. A step in accelerator position is implemented, and the plausibility of the results is assessed.

Implementation:

Chapter 6

Experiments

Project 1C, continued.

This chapter first presents the results of a number of experiments specified in the project compendium. The results are discussed and the plausibility is assessed.

6.1 Acceleration test

6.2 Test run on part of drive cycle

Include figures for: Continuous Lambda, Engine speed, Engine torque, Vehicle Speed VS drive cycle speed

6.3 Simulation of complete drive cycle

Include figures for: Continuous Lambda, Engine speed, Engine torque, Vehicle Speed VS drive cycle speed

6.4 Fuel consumption

6.5 Emissions

Chapter 7

Conclusions

Project 1C, continued.