

MASTER'S THESIS 2020:03

Park Lock Development

Parametrising the Park Lock Mechanism

KARTHIK SWAMI NARAYAN



CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Mechanics and Maritime Sciences
Division of Combustion and Propulsion Systems
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

Park Lock Development
Parametrising the Park Lock Mechanism
KARTHIK SWAMI NARAYAN

© KARTHIK SWAMI NARAYAN, 2020.

Supervisor: Martin Johansson, AVL Vicura
Examiner: Sven Andersson, Department of Mechanics and Maritime Sciences

Master's Thesis 2020:03
Department of Mechanics and Maritime Sciences
Division of Combustion and Propulsion Systems

Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Typeset in L^AT_EX
Printed by Department of Mechanics and Maritime Sciences
Gothenburg, Sweden 2020

Park Lock Development
Parametrising the Park Lock Mechanism
KARTHIK SWAMI NARAYAN
Department of Mechanics and Maritime Sciences
Chalmers University of Technology

Abstract

With increasing focus on fuel consumption and the emergence of electric vehicles, transmissions are becoming more compact. Park Lock Mechanisms are devices that are fitted to vehicles with an automatic transmission or electric vehicles. This mechanism is in place to prevent the unnecessary movement of the vehicle when the vehicle is brought to a stop. Various types of park locks exist today, two of the commonly used variants are investigated in this thesis. One of the major requirements in designing a park lock mechanism is its engagement speed.

The aim of this thesis is to develop a method to parametrise the park lock mechanism and create a common tool program that will help in carrying out the engagement speed analysis of the park lock mechanism.

Keywords: Transmission, Park Lock, Engagement Speed, Parametrisation.

Acknowledgements

This Master Thesis was carried out in the office of AVL Vicura and the Division of Combustion and Propulsion Systems at Chalmers University of Technology. Firstly, I would like to thank my supervisor Dr Martin Johansson for his continuous support during the course of the thesis. His support throughout the thesis is a major reason why I was able to achieve the goals of this thesis. This thesis would not have been possible without his experience, knowledge, guidance and patience. I would also like to thank Per Rosander, Martin Schagerlind, Peyman Jafarian, Farhan Khan, Annelie Linder and the staff at AVL Vicura for always having the time to answer my questions no matter how trivial. I would also like to thank my examiner, Sven B Andersson, for his constant support and constructive feedback throughout the course of the thesis.

Finally, I would like to thank my friends who have stood with me through thick and thin and my parents, to whom I owe everything, for their unconditional support and encouragement.

Karthik Swami Narayan, Gothenburg, January 2020

Contents

List of Figures	xi
List of Tables	xiii
1 Introduction	1
1.1 AVL Vicura	1
1.2 Problem Description	1
1.3 Objective	2
1.4 Methodology	2
1.5 Project Goal	2
2 Theory	3
2.1 Constituents of a Park Lock Mechanism	3
2.2 Anatomy of the Park Lock Mechanism	5
2.2.1 Anatomy of the Actuator	6
2.3 Types of Park Lock Mechanisms	7
2.3.1 Based on the Type of Actuator	7
2.3.2 Based on the Direction of Actuator	9
2.4 Engagement Speed	11
2.5 Engagement Speed Analysis	12
3 Methods	13
3.1 Free-body Diagram of the Actuator	13
3.2 Free-body Diagram of the Pawl	14
3.3 Assumptions	15
3.4 Kinematic Relations	16
3.4.1 Coefficients A and B	18
3.5 Dynamic Equation	20
3.6 Implementation in Matlab	21
4 Results	23
4.1 Generalised Kinematic Relations	23
4.2 Parametrised Park Lock Mechanism	25
5 Conclusion	27
5.1 Future Work	27

List of Figures

2.1	Constituents of a Park Lock Mechanism	4
2.2	Constituents of a Park Lock Mechanism	4
2.3	Anatomy of the Park Pawl	5
2.4	Anatomy of the Actuator	6
2.5	Cone Actuated Park Lock	7
2.6	Roller Actuated Park Lock	8
2.7	Cone From the Pivot	9
2.8	Cone Towards Pivot	10
2.9	Cone Perpendicular to the Pivot	11
3.1	Free-body diagram of the Actuator	13
3.2	Free-body diagram of the Pawl	14
3.3	Tooth-butt	15
3.4	η_{tb}	16
3.5	η_{bc}	16
3.6	η_{ac}	16
3.7	η_p	16
3.8	Schematic of the program	21
4.1	Parametrised Pawl	25

List of Tables

4.1	Control Variables for Different Variants	24
4.2	Key Parameters	24

1

Introduction

Automatic Transmissions in vehicles are becoming the norm today and with the need to reduce fuel consumption, electric vehicles are increasing in number too. As the vehicles get smarter, transmissions have also felt the need to adapt so as to cope with the demands of the 21st century. Apart from providing the user with different driving modes, vehicles with an Automatic Transmission and electric vehicles have a device called a Park Lock. A Park Lock Mechanism is a mechanical device that is placed in automatic and EV (Electric Vehicle) transmissions to prevent the unintentional rollback of the vehicle when the vehicle is brought to a stop. The design of this mechanism is of utmost importance because it has to withstand high forces and torque created by the vehicle and must be able to engage and disengage at will. Therefore, a park lock mechanism needs to be designed for infinite life.

All vehicles with an automatic gearbox are required by law to have a mechanism apart from the service brake to prevent the unintentional rollaway of the vehicle after it has been parked [1]. This was enforced by the National Highway Traffic Safety Administration and the standards are called the Federal Motor Vehicle Safety Administration. The standard pertaining to the park lock mechanism is known as FMVSS 114, which is simply a test procedure which ensures that the park lock is able to prevent the rollback of the vehicle for a distance of 150mm or lesser when the vehicle is brought to a stop on a slope with a gradient of 10%.

1.1 AVL Vicura

AVL Vicura is a company of engineers developing solutions for driveline systems based in Trollhättan, Sweden [2]. This Master Thesis was performed in collaboration with AVL Vicura, who act as the stakeholders of this thesis.

1.2 Problem Description

Today, when a park lock mechanism is designed, it is designed in a way that it not only fits one vehicle variant but many variants (these variants can include either front wheel drive, rear wheel drive, vehicles with varying final gear to park lock gear ratios etc). Therefore, one Park Lock Mechanism needs to satisfy various requirements. Carrying out calculations with different notations for each variant becomes a cumbersome procedure, therefore it is prudent to parametrise the park lock mechanism and have one tool to carry out the necessary calculations.

To analyze a variant of a park lock system, the standard practice is :

- Draw a Free-Body Diagram of the Park Lock System.
- To derive the governing equations of the pawl and the actuators (roller, cone or hydraulic).
- Implementing it on a software (Matlab for example)
- Analyzing the system for stresses and torques it experiences.

1.3 Objective

This method described in section 1.2 seems to work fairly well and the simulations that are run by the stakeholders are fairly less time-consuming. But the problem with this procedure is that every time a variant needs to be analyzed, the above procedure has to be repeated. Additionally, comparing results from the different variants is not possible as different notations have been used and it has not been parameterized.

The objective of this thesis is :

- To have a common tool/program wherein the different actuation methods are implemented.
- Identify the key Parameters involved for the analysis.
- Ensure the parameters used in the model for analysis are aligned to the CAD Model (CAD Model not in the scope of this thesis)
- Have a working model which could then be modified upon requirement of the type of analysis (dimensioning springs etc.)

1.4 Methodology

Work was divided into three stages during the course of this Master Thesis. The first stage was to gain an in-depth knowledge of a park lock mechanism and its constituents. The second stage is to derive the kinematic and dynamic relations in the Park Lock and parametrise the different variants. Once this is accomplished, a common tool is created that can evaluate park lock mechanisms and thereby making results from any variant comparable. The final step is to validate the results from the tool created with previously run simulations.

1.5 Project Goal

The goal of this Master Thesis is to parametrise the Park Lock Mechanism and create a common tool that will account for different actuator types so that comparison between actuator types is possible.

2

Theory

This section describes the theory necessary to understand the Park Lock Mechanism. The constituents of the Park Lock mechanism and the various parts of the park lock mechanism are discussed in this section.

2.1 Constituents of a Park Lock Mechanism

Every park lock mechanism consists of the following parts :

1. *Park Pawl* which is the lever that moves into the gear void.
2. *Actuator* - it is a mechanical member which is responsible for causing the motion of the pawl. The actuator moves linearly along the axis of the actuator rod. The actuator could be in the shape of a cone or could be rollers.
3. *Park Gear* - A notched wheel that is placed on the output shaft in an automatic transmission (could be on either one of the shafts in an EV transmission). The number of teeth and the width of the tooth will determine the rollback distance of the vehicle.
4. *Actuator Rod* - It is a cylindrical member that is connected to the actuator.
5. *Actuator Spring* - It is a spring wound around the actuator rod. The spring is compressed when the park lock is not engaged. Once the Park Lock is engaged, the actuator spring pushes the actuator which then pushes the pawl in the downward direction.
6. *Return Spring* - A spring, called the return spring, is wound around the pawl. The purpose of this spring is to ensure that the pawl is pushed out of the gear void when shifted out of the park position.

The constituents of a Park Lock mechanism can also be seen in figure 2.1.

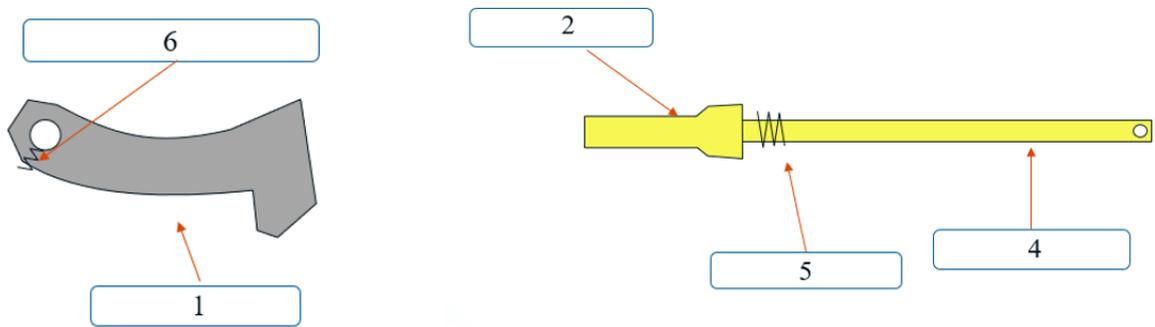


Figure 2.1: Constituents of a Park Lock Mechanism

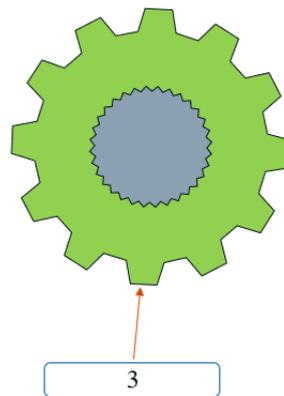


Figure 2.2: Constituents of a Park Lock Mechanism

2.2 Anatomy of the Park Lock Mechanism

During the course of this report, certain parts of the park lock mechanism are going to be discussed in detail. The important parts for this thesis are listed below :

1. *Pawl Pivot Point* - The pivot point of a park lock mechanism is basically the point about which the pawl pivots as seen in figure 2.3.
2. *Pawl Tooth* - The pawl tooth is that part of the pawl that moves into the gear void of the park gear as seen in figure 2.3 .
3. *Lower Ramp* - The lower ramp on the cone actuator of a park lock mechanism is a profile found on the cone which is the first part of the cone to come in contact with the pawl as seen in figure 2.4 .
4. *Upper Ramp* - The upper ramp on the cone actuator of a park lock mechanism is a profile found on the upper part of the cone. This part comes in contact with the pawl when the actuator (cone in this case) completes its actuation stroke as seen in figure 2.4.
5. *Corner Radius* - It is that part on the profile of the actuator that connects the upper ramp to the lower ramp. (For a cone actuated park lock, this part is called a cone corner radius) as seen in figure 2.4.
6. *Support* - The support of the actuator ensures that the actuator stays in place throughout the actuation and the return stroke.

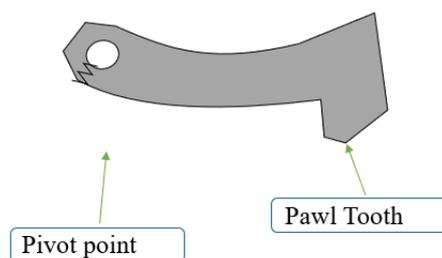


Figure 2.3: Anatomy of the Park Pawl

2.2.1 Anatomy of the Actuator

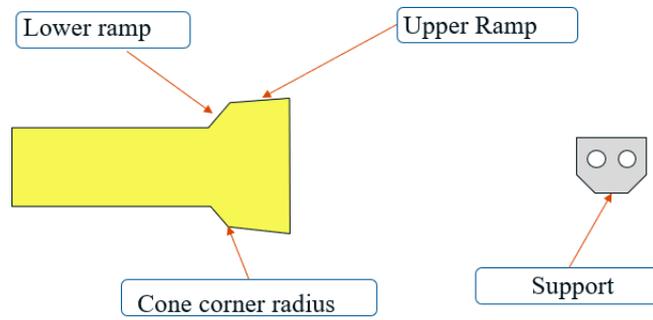


Figure 2.4: Anatomy of the Actuator

2.3 Types of Park Lock Mechanisms

Park Lock Mechanisms can be broadly classified based on the type of actuator used and the direction of the actuator. Both these classification are discussed in the following sections.

2.3.1 Based on the Type of Actuator

Cone Actuated

A cone actuated park lock mechanism, as the name suggests, is one in which the movement of the pawl in to the gear void is carried out by means of a cone. The cone moves linearly along the actuator rod axis, its motion assisted by means of the actuator spring. Cone actuated park lock mechanisms are the most common type of park lock mechanisms found today. A cone actuated park lock mechanism is shown in figure 2.5

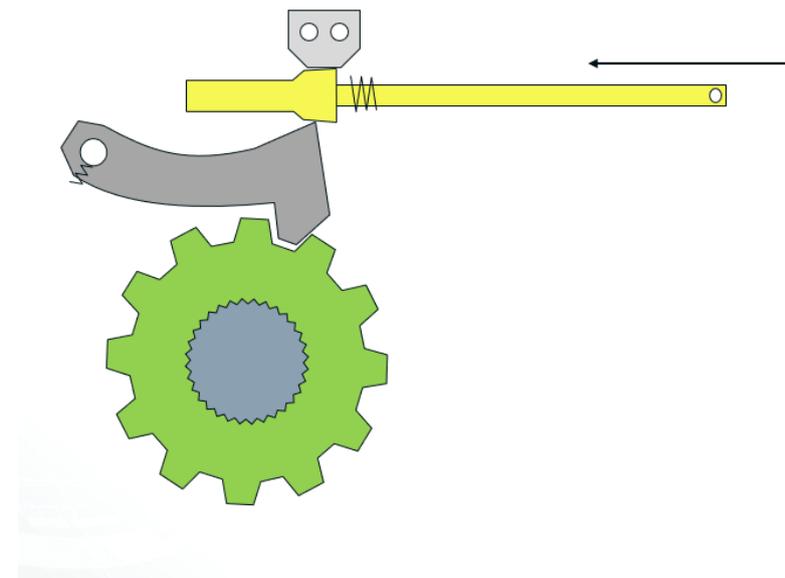


Figure 2.5: Cone Actuated Park Lock

Roller Actuated

Vehicles that have generate high forces (could be either from the electric motors in EV transmissions) usually have a roller actuated park lock mechanism. A pair of rollers are stacked on top of each other and encompassed in a cage which is then connected to the actuator rod. In this case, the corner radius the upper and lower ramps (collectively called the profile) as discussed in section 2.2 are located on the pawl. A roller actuated park lock mechanism is shown in figure 2.6

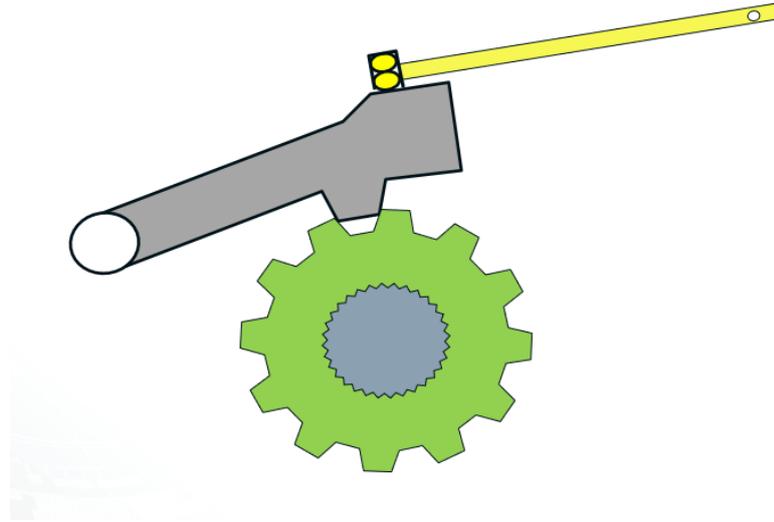


Figure 2.6: Roller Actuated Park Lock

2.3.2 Based on the Direction of Actuator

Cone from the Pivot

In this case, the pivot point of the pawl and the cone are located on the same side, i.e, when the gear shifter is engaged to mode P, the cone starts its actuation stroke towards the pawl (which as a consequence will push the pawl down) from the same side as the pivot point. This type of park lock mechanism is shown in figure 2.7

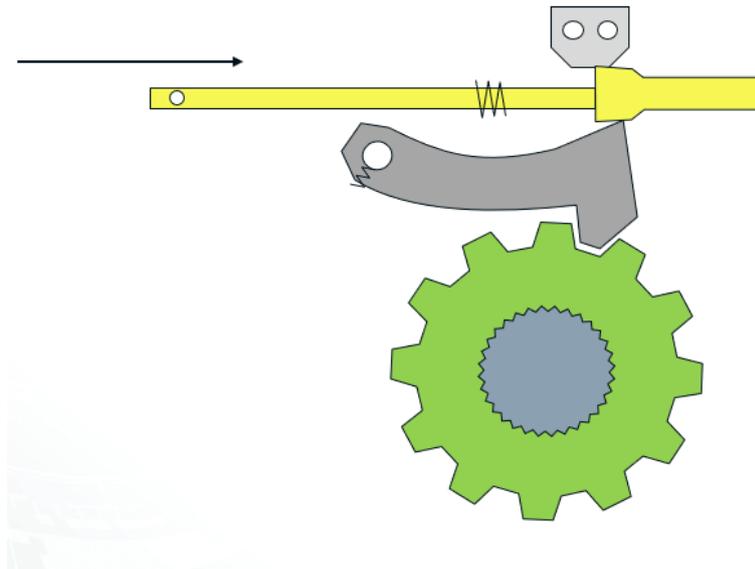


Figure 2.7: Cone From the Pivot

Cone Towards the Pivot

The cone and the pivot point are on the opposite side for this case. Therefore, when mode P is engaged, the cone moves towards the pivot in order to engage the pawl, as seen in figure 2.8

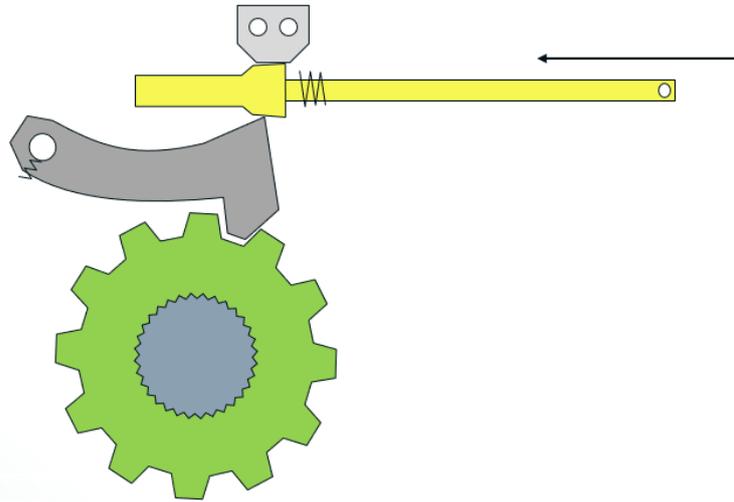


Figure 2.8: Cone Towards Pivot

Cone Perpendicular to the Pivot

As the name suggests, the cone moves towards the pivot in the perpendicular direction. The angle between the pivot point and the axis of the actuator rod is 90° , as seen in 2.9

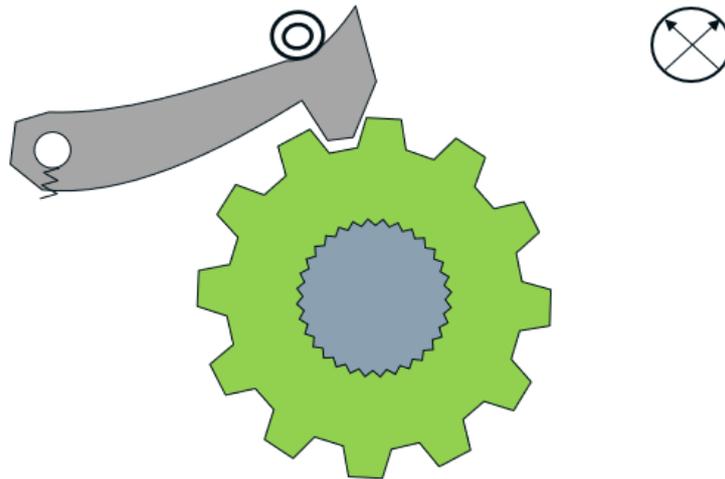


Figure 2.9: Cone Perpendicular to the Pivot

2.4 Engagement Speed

The engagement speed of a Park Lock Mechanism is the speed of the vehicle at which the park lock will engage. There are two limits for the engagement speed, an upper limit above which the park lock will not engage under any circumstance and a lower limit below which the park lock will always engage. Both these limits are equally important, when analysing a park lock mechanism.

The lower limit is necessary when the vehicle is brought to a complete stop and parked in a slope. From the time the driver stops and engages the shifter to P (park), the vehicle will have the tendency to rollback and gain some velocity. Therefore, the lower limit of the park lock should be greater than the velocity gained by the vehicle while rolling back.

The upper limit is necessary to prevent unsafe engagement of the park lock which could then potentially harm and irreparably damage other parts in the transmission. Over this upper limit, the park pawl will begin ratcheting, if the park lock were to be engaged.

As discussed in section 1, the safety standards pertaining to park lock mechanisms is the FMVSS 114 test procedure which stipulates that a park lock mechanism fitted on to a vehicle needs to hold the vehicle parked on a 10% gradient allowing a maximum rollback of 150mm [?].

Given that the regulations on park lock mechanism are vague and that they do not impose any requirements on the engagement speeds, the upper and lower limits for the same are set by customers (these customers could be OEMs who buy a gearbox from a manufacturer or an OEM who outsources the design and analysis to service companies that develops the solutions for them).

2.5 Engagement Speed Analysis

The engagement speed analysis for a park lock mechanism is carried out in five stages:

- Draw the Freebody Diagram of the Pawl and the Actuator
- Derive the equations of motion for the pawl and the actuator
- Derive the dynamic equation and the kinematic describing the motion of the pawl and the actuator respectively, in the form of an ordinary differential equation.
- Implement these equations on Matlab to solve the ordinary differential equations.
- A time-history of the cone or the pawl can be obtained in the form of plots which can then analysed further.

3

Methods

The approach taken to parametrise the park lock mechanism, drawing the free-body diagram of the actuator and the pawl and deriving the equations of motion of the same, establishing a kinematic relation between the actuator and the pawl and deriving a dynamic equation are all explained in this section.

3.1 Free-body Diagram of the Actuator

The free-body diagram of the cone actuator is seen in figure 3.1.

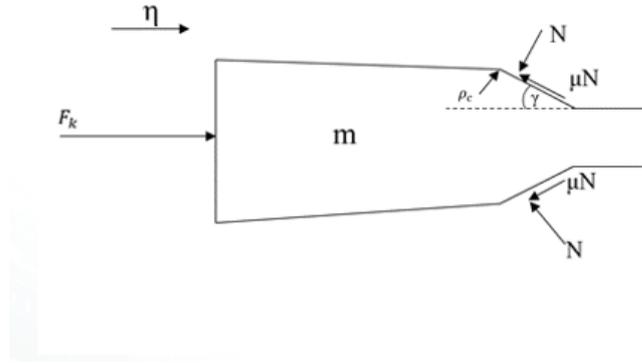


Figure 3.1: Free-body diagram of the Actuator

1. η describes the motion of the cone as it goes from being disengaged to engaged.
2. F_k is the actuation force from the spring.
3. ρ_c is the cone corner radius.
4. γ is the ramp angle of the cone.
5. m is the mass of the cone.
6. N is the contact force normal to the cone profile.
7. μ is the coefficient of friction.

Using the method of force balance, the equation of motion of the cone can now be derived and that is given by:

$$m\ddot{\eta} = F_k(\eta) - 2N(\sin\gamma - \mu\cos\gamma) \quad (3.1)$$

3.2 Free-body Diagram of the Pawl

The free-body diagram of the pawl is shown in figure 3.2

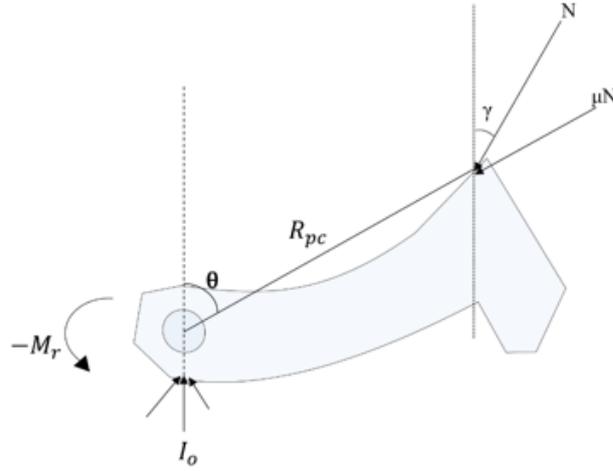


Figure 3.2: Free-body diagram of the Pawl

1. θ describes the motion of the pawl as it goes from being disengaged to engaged.
2. I_o is the moment of inertia of the pawl.
3. R_{pc} is the distance from the pivot point to the point of contact of the actuator on the pawl.
4. $-M_r$ is the pre-load force of the return spring.

Once again, by using the methods of force balance, the equation of motion for the pawl is given by:

$$I\ddot{\theta} = -M_r + NR_{pc}(\cos\gamma - \mu\sin\gamma) \quad (3.2)$$

3.3 Assumptions

Before deriving the kinematic relations, it was necessary to list out some assumptions that would help simplify the process as well as limit the scope of the analysis. The assumptions are:

1. The analysis starts from the point known as tooth-butt. Tooth-butt is that point where, the shifter has been engaged, the actuator has begun its stroke towards (or from) the pivot and the pawl is resting directly on top of the gear tooth. The condition of tooth-butt can be seen in figure 3.3.
2. The cone is symmetric about its own axis.
3. The actuator and the pawl are always in contact.
4. The actuation spring is compressed.
5. The angle between the actuator and the pivot point is constant.
6. The motion of the pawl in to the gear void is by virtue of the actuator motion only. The engagement is ideal and no other forces (either from the vehicle or the road) is considered.
7. The contact from the support to the actuator and the actuator to the pawl are in a straight line.

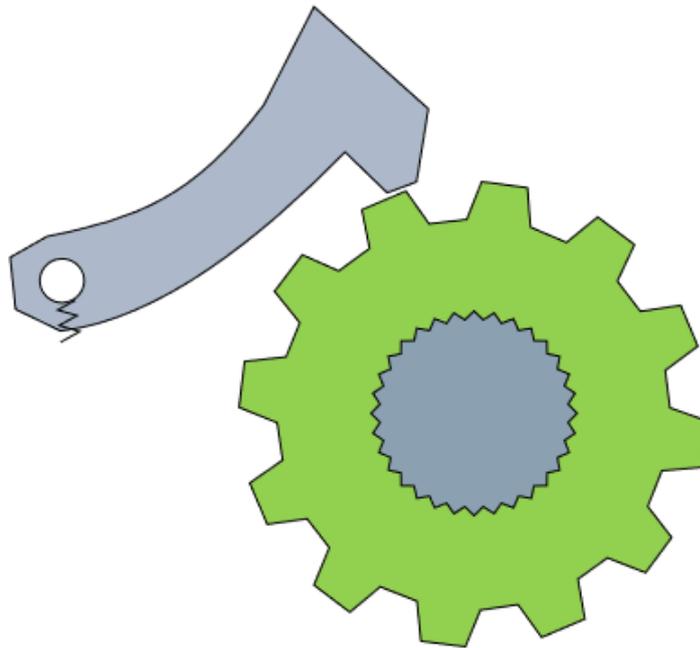


Figure 3.3: Tooth-butt

3.4 Kinematic Relations

From the freebody diagrams of the actuator and the pawl, seen in sections 3.1 and 3.2 respectively, it can be seen that there are two degrees of freedom existing in the park lock mechanism, namely:

- Rotational degree of freedom of the pawl.
- Linear degree of freedom of the actuator.

Since it is assumed that both these bodies are in contact with each other throughout the scope of the analysis, it is then possible to eliminate one degree of freedom and express it in terms of the other.

Four points are taken into consideration while carrying out the analysis. These four points are shown in figures 3.4, 3.5, 3.6 and 3.7.

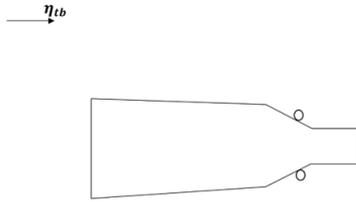


Figure 3.4: η_{tb}

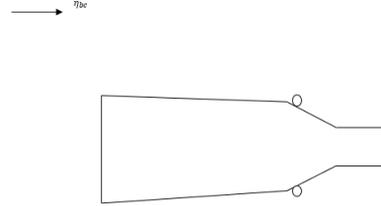


Figure 3.5: η_{bc}

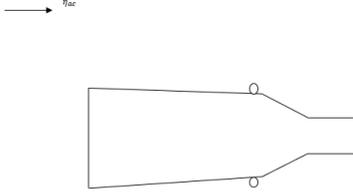


Figure 3.6: η_{ac}

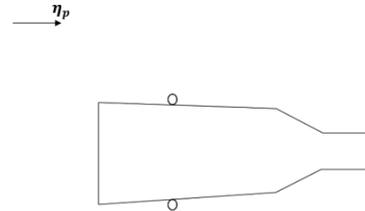


Figure 3.7: η_p

These four points are chosen because it is these that are of utmost interest while carrying out the engagement speed analysis. The first and the last points, η_p and η_{tb} are self-explanatory, it was discussed earlier that the analysis starts at tooth butt and ends at P. The other two points, one after the corner and one before are chosen because it is extremely important to have mathematical equations describe the motion in the most dynamic part of the profile, which is the corner (cone corner radius).

As we know, η describes the motion of the actuator. The kinematic equation describing the motion of the actuator as it goes from tooth butt to P, is given by:

$$\ddot{\eta} = A(\theta)\ddot{\theta} + B(\theta)\dot{\theta}^2 \quad (3.3)$$

The coefficients A and B change depending on the point on the profile of the actuator.

To derive the coefficients A and B, the four points shown above are considered. The first step is to calculate the distance between the contact from the support to the actuator and the actuator to the pawl for all of the four points.

At η_p the distance between the contact from the support to the actuator and the actuator to the pawl is given by:

$$2(r_p + \rho_p * \cos\gamma_1) \quad (3.4)$$

where r_p is the radius of the cone at P, ρ_p is the radius of the contacts, both at the pawl and the support.

At, η_{bc} , the distance between the contact from the support to the actuator and the actuator to the pawl is given by:

$$2(r_1 + \rho_p * \cos\gamma_1) \quad (3.5)$$

which can further be written in terms of r_p and ρ_p as

$$2((r_p - l_1 * \tan\gamma_1) + \rho_p * \cos\gamma_1) \quad (3.6)$$

where l_1 is the distance to the cone corner radius. This equation can be further broken down in terms of the parameters concerning the pawl, namely, R_{pc} and θ , the the distance from the pivot point to the point of contact of the actuator on the pawl and the angular stroke of the pawl respectively, as:

$$- R_{pc}(\theta_p - \theta_a) + 2((r_p + \rho_p * \cos\gamma_1)) \quad (3.7)$$

At, η_{ac} , the distance between the contact from the support to the actuator and the actuator to the pawl is given by:

$$2(r_2 + \rho_p * \cos\gamma_2) \quad (3.8)$$

which can further be written in terms of r_p and ρ_p as

$$2(r_1 + \rho_p * \cos\gamma_1 - (\rho_p + \rho_c)(\cos\gamma_1 - \cos\gamma_2)) \quad (3.9)$$

This equation can once again be further broken down in terms of the parameters concerning the pawl, namely, R_{pc} and θ , the the distance from the pivot point to the point of contact of the actuator on the pawl and the angular stroke of the pawl respectively, as:

$$- R_{pc}(\theta_p - \theta_1)\cos\theta_a + 2((r_p + \rho_p * \cos\gamma_1)) \quad (3.10)$$

Once this is completed, these distances for the various points are then equated to find out the coefficients A and B.

3.4.1 Coefficients A and B

Between η_{bc} and η_p

$$\eta_p - \eta_{bc} = l_1 \quad (3.11)$$

We also know that at η_{bc} , the distance between the contact from the support to the actuator and the actuator to the pawl is given by:

$$-R_{pc}(\theta_p - \theta_a) + 2((r_p + \rho_p * \cos\gamma_1)) \quad (3.12)$$

The same distance at η_p is

$$2(r_p + \rho_p * \cos\gamma_1) \quad (3.13)$$

Since,

$$\eta_p - \eta_{bc} = l_1 \quad (3.14)$$

$$\eta_p - l_1 = \eta_{bc} \quad (3.15)$$

$$2(r_p + \rho_p * \cos\gamma_1) - l_1 = -R_{pc}(\theta_p - \theta_a) + 2((r_p + \rho_p * \cos\gamma_1)) \quad (3.16)$$

The distance to the corner radius, l_1 , at any instant η can be given by

$$2(\eta_p - \eta)\tan\gamma_1 \quad (3.17)$$

Therefore, equation 3.16 can be rewritten as:

$$2(r_p - (\eta_p - \eta)\tan\gamma_1 + \rho_p * \cos\gamma_1) - l_1 = -R_{pc}(\theta_p - \theta_a) + 2((r_p + \rho_p * \cos\gamma_1)) \quad (3.18)$$

On simplifying equation 3.18 we get,

$$-2((\eta_p - \eta)\tan\gamma_1) = -R_{pc}(\theta_p - \theta)\cos\theta_a \quad (3.19)$$

If $\eta_p - \eta = \Delta\eta$ and $\theta_p - \theta = \Delta\theta$, then

$$\Delta\eta = \frac{R_{pc} * \cos\theta_a}{2\tan\gamma_1} * \Delta\theta \quad (3.20)$$

This can also be written as:

$$\dot{\eta} = \frac{R_{pc} * \cos\theta_a}{2\tan\gamma_1} * \dot{\theta} \quad (3.21)$$

On differentiating equation 3.21 again,

$$\ddot{\eta} = \frac{R_{pc} * \cos\theta_a}{2\tan\gamma_1} * \ddot{\theta} \quad (3.22)$$

Note that in equation 3.22, all the other values are constant except θ

The coefficients of $\dot{\theta}$ and $\ddot{\theta}$ in equations 3.21 and 3.22 respectively are the values of A and B at this point

Similar steps are carried out for the other points.

The coefficients A and B between each of the points are shown below.

1. Between the points η_{bc} and η_p , the coefficients A and B are:

$$A = \frac{R_{pc} \cos \theta_a}{2 \tan \gamma_1} * (1 - (\theta_p - \theta_a) \tan \theta_a) \quad (3.23)$$

$$B = \frac{R_{pc} \cos \theta_a}{2 \tan \gamma_1} * (\theta_p - \theta) \quad (3.24)$$

2. Between the points η_{ac} and η_{tb} , the coefficients A and B are:

$$A = \frac{R_{pc} * \cos \theta_a}{2 \tan \gamma_2} * (1 - (\theta_p - \theta_a) \tan \theta_a) \quad (3.25)$$

$$B = \frac{R_{pc} * \cos \theta_a}{2 \tan \gamma_2} * (\theta_p - \theta) \quad (3.26)$$

3. Between the points η_{bc} and η_{ac} , the coefficients A and B are:

$$A = \frac{C_f}{C_g} * \frac{f}{\sqrt{1 - f^2}} \quad (3.27)$$

$$B = \frac{(C_f)^2}{C_g} * \frac{1}{\sqrt[3]{(1 - f^2)^2}} \quad (3.28)$$

where,

$$f = \cos \gamma_1 - \frac{R_{pc}}{2(\rho_p + \rho_c)} * \cos \theta_a * (\theta_p - \theta) + \frac{(\eta_p - \eta_1) * \tan \gamma_1}{(\rho_p + \rho_c)} \quad (3.29)$$

$$C_f = \frac{R_{pc}}{2(\rho_p + \rho_c)} * \cos \theta_a \quad (3.30)$$

and

$$C_g = \frac{1}{(\rho_p + \rho_c)} \quad (3.31)$$

From the above coefficients and the equations, it can be seen that, the motion of the actuator is now described by the motion of the pawl, thereby eliminating one degree of freedom. Similar derivations were done for all the other cases and the coefficients A and B at each of the points for all the cases are examined and then generalised. The generalised version of these equations are presented in the results section of the report.

3.5 Dynamic Equation

Once the kinematic equations of the actuator are derived, it is necessary to derive the equation of the pawl in the form of an Ordinary Differential Equation, which would then be solved on Matlab.

Revisiting the equation derived in section 3.1, the equation of motion of the actuator was

$$m\ddot{\eta} = F_k(\eta) - 2N(\sin\gamma - \mu\cos\gamma) \quad (3.32)$$

Rearranging this equation to get an expression for the Normal force, N would give:

$$N = \frac{F_k(\eta) - m\ddot{\eta}}{2(\sin\gamma - \mu\cos\gamma)} \quad (3.33)$$

The equation of motion of the pawl according to equation 3.2 is

$$I\ddot{\theta} = -M_r + NR_{pc}(\cos\gamma - \mu\sin\gamma) \quad (3.34)$$

Also, the kinematic equation of the actuator is given by

$$\ddot{\eta} = A(\theta)\ddot{\theta} + B(\theta)\dot{\theta}^2 \quad (3.35)$$

Substituting the value of N obtained in equation 3.33 and the kinematic equation of the actuator (equation 3.3), would then yield,

$$I\ddot{\theta} = -M_r + (F_k(\eta) - m(A(\theta)\ddot{\theta} + B(\theta)\dot{\theta}^2)) \cdot \frac{R_{pc}(\cos\gamma - \mu\sin\gamma)}{2(\sin\gamma - \mu\cos\gamma)} \quad (3.36)$$

Rearranging this equation, we get:

$$(I + m * A(\theta) * R_{pc} * \Lambda(\gamma)) * \ddot{\theta} = -m * B(\theta) * R_{pc} * \Lambda(\gamma) * \dot{\theta}^2 - M_r + (F_k(\eta) * R_{pc} * \Lambda(\gamma)) \quad (3.37)$$

If

$$(I + m * A(\theta) * R_{pc} * \Lambda(\gamma)) = C \quad (3.38)$$

and

$$-m * B(\theta) * R_{pc} * \Lambda(\gamma) = D \quad (3.39)$$

the, the dynamic equation of the pawl is given by,

$$\ddot{\theta} = \frac{D}{C} * \dot{\theta}^2 - \frac{M_r}{C} + \frac{F_k(\eta) * R_{pc} * \Lambda(\gamma)}{C} \quad (3.40)$$

where

$$\Lambda(\gamma) = \frac{\cos\gamma - \mu\sin\gamma}{2(\sin\gamma - \mu\cos\gamma)} \quad (3.41)$$

3.6 Implementation in Matlab

Having obtained the dynamic equation of the pawl, it is then solved on Matlab using its ode solvers. A small pre-processing step was incorporated so that the numerical values (like R_{pc} , etc) that Matlab would require to solve the equation, would be handled seamlessly. This pre-processing step would also help in changing the park lock type so that it would facilitate the comparison of different park lock variants. A schematic of the program is shown below,

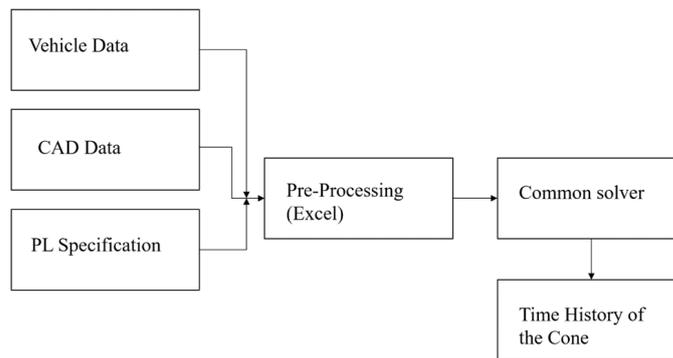


Figure 3.8: Schematic of the program

4

Results

The results of the parametrisation are described in this section. A parametrised version of the Park lock mechanism is also shown.

4.1 Generalised Kinematic Relations

The procedure followed in section 3.4.1 is carried out for all the variants of the park lock mechanism discussed in section 2.3. The coefficients obtained following this procedure are then examined to analysed the differences and similarities and then a general expression is then derived which would then work for all the said variants.

1. The generalised coefficients A and B between the points eta_{bc} and η_p is given by:

$$A = \frac{R_{pc} \cos \theta_a * \alpha * (1 - ((\theta_p - \theta) \tan \theta_a) T)}{\tan \gamma_1} \quad (4.1)$$

$$B = \frac{R_{pc} \cos \theta_a * \alpha * (\theta_p - \theta)}{\tan \gamma_1} \quad (4.2)$$

2. The generalised coefficients A and B between the points eta_{ac} and η_{tb} is given by:

$$A = \frac{R_{pc} \cos \theta_a * \alpha * (1 - ((\theta_p - \theta) \tan \theta_a) T)}{\tan \gamma_2} \quad (4.3)$$

$$B = \frac{R_{pc} \cos \theta_a * \alpha * (\theta_p - \theta)}{\tan \gamma_2} \quad (4.4)$$

3. The generalised coefficients A and B between the points η_{ac} and η_{bc} is given by:

$$A = \frac{C_f}{C_g} * \frac{f}{\sqrt{1-f^2}} \quad (4.5)$$

$$B = \frac{(C_f)^2}{C_g} * \frac{1}{\sqrt[3]{(1-f^2)^2}} \quad (4.6)$$

where

$$f = \cos\gamma_1 - \frac{\alpha * R_{pc}}{(\rho_p + \rho_c)} * \cos\theta_a * (\theta_p - \theta) + \frac{(\eta_p - \eta_{bc}) * \tan\gamma_1}{(\rho_p + \rho_c)} \quad (4.7)$$

$$C_f = \frac{R_{pc}}{(\rho_p + \rho_c)} * \cos\theta_a * \alpha \quad (4.8)$$

and

$$C_g = \frac{1}{(\rho_p + \rho_c)} \quad (4.9)$$

In the above equations, two new variables are introduced, namely α and T. These variables are control variables which are written into the Matlab script that would allow the user to toggle between different variants. The values of α and T are illustrated in the table below :

Table 4.1: Control Variables for Different Variants

Park Lock Variant	α	T
Cone From Pivot	1/2	+1
Cone Perpendicular to Pivot	1/2	-1
Cone Towards Pivot	1/2	-1
Roller Towards Pivot	1	-1
Roller From Pivot	1	+1

The key parameters needed to carry out the engagement speed analysis :

Table 4.2: Key Parameters

Parameter	Symbol
Pivot Point to Actuator Contact	R_{pc}
Angular stroke of the Pawl	θ_p
Angle between Pivot point to actuator axis	θ_a
Ramp angle(s)	γ_i
Actuator spring preload	F_k
Actuator spring stiffness	K
Coefficient of friction	μ

4.2 Parametrised Park Lock Mechanism

The parametrised park lock mechanism is seen in figure 4.1

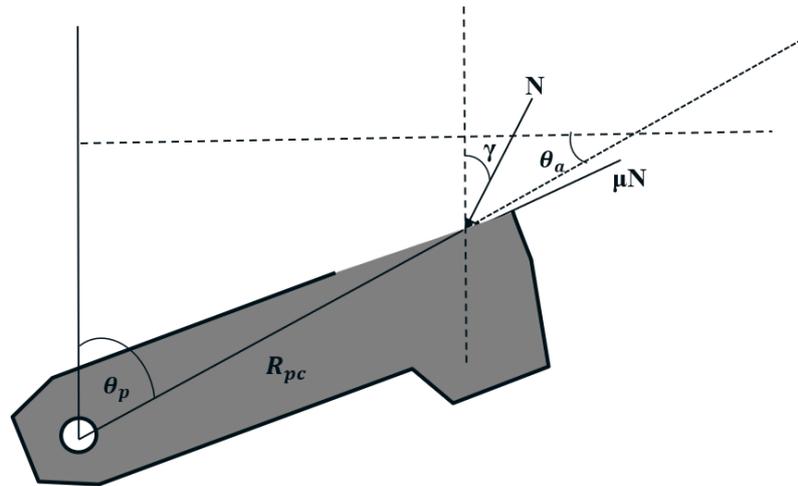


Figure 4.1: Parametrised Pawl

The idea behind this diagram is that the parameters represented in this picture are the necessary parameters to carry out the engagement speed analysis. Therefore, irrespective of the profile on top of the pawl, as long as these values are obtained, an engagement speed analysis can be carried out.

5

Conclusion

The Park Lock Mechanism was parametrised and a common solver program was built on Matlab. The different variants that were taken into consideration were all brought into the scope of the program and the key parameters required to carry out the engagement speed analysis were identified. The key deliverables that were listed during the planning phase of the Master Thesis were met.

- To have a common tool/program wherein the different actuation methods are implemented.
- Identify the key Parameters involved for the analysis.
- Ensure the parameters used in the model for analysis are aligned to the CAD Model (CAD Model not in the scope of this thesis)
- Have a working model which could then be modified upon requirement of the type of analysis (dimensioning springs etc.)

5.1 Future Work

- The scope of the common tool/program can be increased by bringing in more actuator types, for example, cam operated or a combination of cylinder and a cone, which are also in use today.
- The program could also account for standard actuator and return springs which will then decrease the lead time during the concept generation phase.
- The results obtained from running simulations on this program could be validated against results from benching an actual park lock subjected to the same loads resulting in a Hardware in the Loop system.
- The scope of the program could also be increased by bringing in other parameters that are equally important in order to analyse the Park Lock Mechanism, for instance, pull out forces.

Bibliography

- [1] (2019). Retrieved 15 February 2019, from <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/tp-114-04.pdf>
- [2] Avl-vicura.se. (2019). Vicura overview - Vicura. [online] Available at: <http://www.avl-vicura.se/en/about-vicura/vicura-overview> [Accessed 3 Sep. 2019].
- [3] Private conversations with Martin Johansson [February, March and April, 2019]

