CAE Tool for Evaluation of Park Lock Mechanism in a DCT Transmission

CAE verktyg för utvärdering av parkeringslåsmekanism i en växellåda med dubbla kopplingar

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ABSTRACT

A park lock mechanism is a device that is fitted to an automatic transmission on a vehicle. The mechanism lock up the transmission so that no rolling of the vehicle can be done when the vehicle is put in the park position.

The aim of this thesis is to develop a method in order the evaluate designs on a Park Lock Mechanism (PLM) that can be found in a dual clutch transmission (DCT).

A Computer Aided Engineering (CAE) tool to calculate the output that is required for an evaluation of a park lock mechanism design will be created. The CAE tool shall calculate static, dynamic, and snap torque on a ratchet wheel in a gradient, with or without a trailer, also the minimum and maximum coefficient of friction between the pawl and cone, pull out force, the maximum amount of rollback, torque needed from the return spring, preload force from actuator spring, and engagement speed.

The CAE tool created uses an Excel Visual Basics for Applications (VBA) workbook for all calculations. The tool allows the user to choose different vehicles with the required specification to evaluate the values for that PLM.

The CAE tool will save time and cost if lots of different PLM's are going to be designed. The CAE tool has potential for future work when more calculations can be added that can be in use for the evaluation the PLM.

The CAE tool developed by the master thesis student calculates all the required values for evaluation of a PLM design, executed in a fast, efficient, and easy to use program.

SAMMANFATTNING

En parkeringslåsmekanism är en enhet som är monterad på en automatisk växellåda på ett fordon. Mekanismen låser växeln så att fordonet inta kan rulla när bilen sätts i parkeringspositionen.

Syftet med denna avhandling är att utveckla en metod för att utvärdera konstruktioner på en pakeringslåsmekanism (PLM) som finns i en dubbelkopplingstransmission.

Ett datorstött verktyg (CAE) som beräknar alla värden som krävs för att utvärdera konstruktionen av en parkeringslåsmekanism ska tas fram. CAE-verktyget ska beräkna statiskt, dynamiskt och ögonblicksmoment på spärrhjulet i en lutning, med eller utan släpvagn, minsta och maximala friktionskoefficient mellan spärrhake och kon, utdragskraft, maximal tillbakarullning, vridmoment som krävs från returfjädern, förspänningskraften från fjäderställdon och ingreppshastigheten.

Det framtagna CAE-verktyget använder en Excel Visual Basic for Applications (VBA) arbetsbok för alla beräkningar. Verktyget låter användaren välja mellan olika fordon med den angivna specifikationen för att utvärdera värdena för just den PLM.

CAE-verktyget sparar tid och kostnad om många olika PLM kommer att konstrueras. CAE-verktyget har potential för framtida förbättringsarbete då fler beräkningar kan läggas till och användas för utvärderingen av PLM.

CAE-verktyget utvecklat av examensarbetsstudenten beräknar alla nödvändiga värden för utvärdering av en PLM konstruktion, som utförs i ett snabbt, effektivt och lättanvänt program.

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NOMENCLATURE

F	Force
F_g	Force from vehicle on slope
F_f	Friction force
F_t	Traction force
F_n	Normal force
F_a	Aerodynamic friction
F_r	Rolling resistance
$F_{braking}$	Resulting force from braking
F_d	Summarize disturbance force of not yet specified effects
F_p	Force acting on pawl from the ratchet wheel
$F_{pullout}$	Force needed to pull out the cone when engaged position
$F_{avg,actuator,spring}$	Average force needed to put pawl into engaged position
τ	Torque
τ_r	Torque on ratchet wheel
$\tau_{dyn,wheel}$	Dynamic torque on wheel
$\tau_{snap,ratchet}$	Dynamic torque on wheel
τ_w	Torque on wheel
$\tau_{r,s}$	Torque that return spring must produce
m_v	Mass of the vehicle
m_{pawl}	Mass of the pawl
g	Gravitational acceleration
a_{st}	Resulting acceleration from gravitational acceleration acting on the vehicle
$a_{braking}$	Resulting acceleration from braking
$a_{friction}$	Acceleration from friction
$a_{max,g}$	Maximum acceleration acting on the vehicle
t	Time
$t_{braking}$	Time while braking
t_{open}	Time that pawl has to engage
r	Radius
r_w	Radius on wheel
$r_{ratchet}$	Radius on ratchet wheel to the rounding of the tooth
R	Gear ratio
ω	Angular velocity
ω_{wheel}	Angular velocity on the wheel of the vehicle
$\omega_{ratchet}$	Angular velocity on the ratchet wheel
I	Moment of inertia
I_{pawl}	Moment of inertia on pawl in rotation centre
α	Angular acceleration
α_{pawl}	Angular acceleration needed to engage pawl
α_{St}	Slope angle
μ	Coefficient of friction

μ_S	Static coefficient of friction
μ_p	Coefficient of friction plough
μ_a	Coefficient of friction abrasive
$\mu_{pawl,cone}$	Coefficient of friction between pawl and cone
θ	Angle
$\theta_{max,ratchet}$	Maximum degrees which ratchet wheel can turn when parking pawl is engaged
$\theta_{max,Wheel}$	Maximum degrees which wheel can turn when parking pawl is engaged
$\theta_{uphill,downhill}$	Degrees rotation on ratchet wheel when vehicle goes from uphill to downhill
θ_{lift}	Degrees on pawl that lift the pawl into engaged position
θ_{lock}	Degrees on the cone that locks the pawl into engaged position
$\theta_{engaged,pawl}$	Radians that pawl travel to engaged position from when the pawl touch the ratchet wheel
θ_{tan}	Degrees between the pawl is position through the centre of gravity to the centre of rotation and the horizon
υ	Velocity
υ_0	initial velocity
$\upsilon_{max,snap}$	Maximum velocity which the vehicle can reach when parking pawl is engaged from zero m/s when snap case
$\upsilon_{max,dyn}$	Maximum velocity which the vehicle reach for dynamic case
n	Number of teeth on ratchet wheel
$d_{pawl,cone}$	Distance between the rotation point of pawl to centrum of cone
$d_{max,wheel}$	Maximum distance which the vehicle can roll when parking pawl is engaged
$d_{F,r}$	Lever between the rotation point of pawl to the tangential force acting from ratchet wheel
$d_{pawl,CoF}$	Distance between the rotation point of pawl to centre of gravity on pawl
y_{tot}	Total lift in y-direction
x_1, x_2	Distance in x-direction on cone
x_{tot}	total distance travelled by fork
R_z	Surface roughness
R_a	Surface roughness
R_n	Surface roughness (n=1,2,3…9,10)
L	Length of the tested area
z	Height of the tops on the surface
A_p	Area of ploughing
A_{lb}	Area from above
H	Hardness

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1 INTRODUCTION

Vehicles with an automatic gearbox are regulated by law to have a mechanism in addition to the usual handbrake that prevents rollaway after it has been parked [1]. The mechanism must withstand high torque created by the vehicle and must therefore be designed to be robust enough to hold for the life time of usage and not be able to self-disengage.

1.1 CEVT

CEVT stands for China Euro Vehicle Technology. CEVT is a relatively new car developer which was founded in 2013 and the company is located at Lindholmen in Gothenburg. CEVT is a subsidiary of the Chinese automotive manufacturer Geely, which also owns Volvo Cars. Since Geely today makes so-called budget cars and Volvo makes premium cars, Geely desired to have something in between the brands. CEVT got the assignment to develop the new car brand Lynk & Co. The first car out on the market will be Lynk & Co 01 which is built on CEVT's Compact Modular Architecture (CMA) platform [2]. This platform will also be used in future Volvo cars [3].

1.1.1 PROPULSION SYSTEM

This thesis was carried out in the propulsion system department at CEVT. Propulsion system is the department which is in charge of everything related to taking the vehicle forward, backward or standing still after parked. The propulsion system department is divided into different areas where transmission is one of them.

1.1.2 SEVEN SPEED DUAL CLUTCH TRANSMISSION

7DCT account for 7-speed Dual Clutch Transmission. A DCT function as two manual gearboxes with two output shafts which automatically selects the gears in advance. For the first output shaft; second, fourth, sixth and reversed gears can be found and for the second output shaft; first, third, fifth and seventh gear including parking lock mechanism can be found [4].

1.2 PROBLEM DESCRIPTION

CEVT is the owner of their own 7DCT. For further development of the 7DCT to fit future vehicles, modifications need to be done on the park lock mechanism to fit the new requirements. CEVT doesn’t have the resource to make calculations on all new PLM’s thus they need a tool for these kind of calculations on the PLM.

1.3 ASSUMPTIONS

The calculations are from ideal cases e.g. 100% efficiency in the gearbox and differential, perfect contact points and no sliding of tires. Small differences between calculated and tested results may occur. Calculations are simplified but it is considered to have little impact on the result. Things that have been neglected are friction between pawl and shaft/bracket, friction between the cone and actuator rod when cone engaging the pawl into parked position, no suspension or damping occurs, aerodynamic friction due to small velocities, perfect fit for cone on actuator rod. The vehicle is assumed to be a front-wheel drive vehicle so the PLM will only affect the front wheels of the vehicle.

1.4 PURPOSE AND GOAL

The purpose and goal of the thesis is to develop a Computer-Aided Engineering (CAE) tool in the form of an Excel program. The program should take input data about the geometry and give out what forces the new geometry will be exposed to. These values can later be used as a background for Finite Element Method (FEM) analysis.

1.5 CARS

The cars powertrain uses many parts to propel the car. The parts included in the powertrain are engine, clutch, transmission, differential, drive shafts and wheels. The engine gives torque through the clutch to the transmission which changes the gear ratio and therefore the torque. The torque from the transmission continues through the differential that provides torque to the wheels. The final drive is the gear ratio from the differential [5]. In this thesis it’s the other way around. A car parked in a slope causes a reaction force that wants to propel the car down the slope. A park lock mechanism will prevent rollaway by taking up the reaction forces.

1.6 TRANSMISSION

The transmission on a vehicle takes the output power from an engine and gives the correct torque to the output shaft which makes the wheels rotate to propel the vehicle or to have the vehicle stationary with the engine still running. Today there are two different kinds of transmissions in vehicles. There is the manual transmission where the user of the vehicle needs to manually shift between gears and the automatic gearbox which makes the shifting for the user. The automatic gearbox comes in a lot of variations like a dual clutch transmission (DCT) or planetary automatic transmission [6]. The transmission in this thesis is about the dual clutch transmission.

1.7 DUAL CLUTCH TRANSMISSION

The DCT resolved problems that planetary automatic transmissions have like efficiency drop due to the torque-converter [4]. The DCT is an automatic transmission that operates two manual gear sets with two clutches. One clutch and gear set is set at odd gears and the other is set at even gears. This is often packed coaxial to reduce the volume of the transmission. While one clutch is engaged the other clutch and gear set will preselect a target gear. In the gearshift one clutch will disengage in the same time as the other clutch will engage to make a seamless gearshift. This will make the vehicle to never have any torque drops and a steady acceleration. The clutches can either be wet clutches or dry clutches [6]. The wet clutch uses oil as a cooling fluid because heavy torque produces heat [7]. The gear shifting is made by a gear actuator and the clutch is operated by a hydraulic clutch actuator (HCA). When the vehicle is parked both HCA that controls the clutches will disengage the clutches. This will make the vehicle rollaway if any external force is applied to the vehicle. To prevent this, a park lock mechanism is fitted to the transmission.

1.8 PARK LOCK MECHANISM

The park lock mechanism (PLM), is put on one of the output shafts in the transmission to prevent any kind of rolling of the vehicle when the vehicle is put in the “park” position [8]. The PLM is by U.S. law regulated on vehicles with automatic transmission that weighs 4536kg or less. The law is for theft protection to reduce incidences of crashes that are a result form an unauthorized use of the vehicle and to reduce the incidences of crashes resulting from rollaway of a parked vehicle with an automatic transmission [1]. The Federal Motor Vehicle Safety Standards (FMVSS) 114 doesn’t say anything about the solution of preventing the rollaway of the vehicle and the park lock mechanism is one solution to the problem.

The park lock mechanism investigated in this thesis consists of a pawl, ratchet wheel, actuator and a cone that pushes the pawl into lock, see Figure 1 [9], [10] and [11]. The vehicle, when moving at a high speed and the park position is engaged, the park pawl must not engage into the ratchet wheel but instead slip until the vehicle is slowed down until the engagement speed is reached. Locking up the parking mechanism at higher speeds causes high stresses, wear, fatigue, and failure on the park lock and on other transmission components.

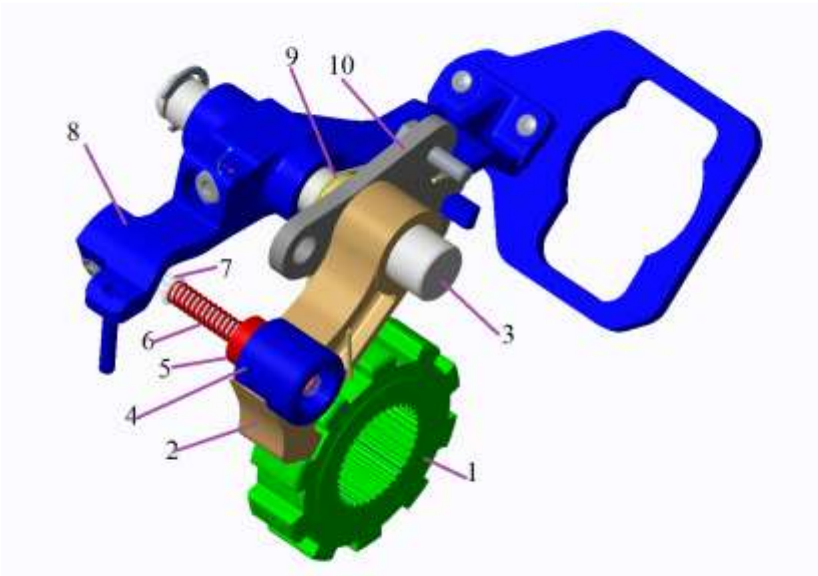

Figure 1. Park lock mechanism, (1) ratchet wheel, (2) pawl, (3) shaft, (4) guide block, (5) cone, (6) actuator spring, (7) actuator rod, (8) fork, (9) return spring, (10) bracket.

Figure 2. Schematic picture on rollback on the PLM, both rollaway when park up the slope and down the slope.

When the driver parks the vehicle in a slope the PLM must prevent rollback before the maximum rollback distance is reached to stop the vehicle, see Figure 2. This also means that the speed that the vehicle is reaching before the park pawl is engaged must be less than the park lock's engagement speed. The speed that the vehicle will reach is a result from approximately one tooth passing on the ratchet wheel. The PLM must be able to disengage when the vehicle has been parked on a slope for an extended period of time, must stay engaged when the pawl has reached the engaged position and must be designed not to disengage while in engaged position.

The gear actuator is the component that selects the gear or puts the vehicle in parked position. The gear actuator goes through the hole on the fork, see Figure 1. When the gear actuator turn to select parking position, the fork on the PLM is displaced so that the spring actuator with the cone is pushed against the guide block and the pawl. The guide block is stationary but the pawl will rotate to engage position. When the fork has done a full displacement, the pawl is in parked position and will lock up the transmission, see Figure 3.

Figure 3. To the left, PLM disengaged. To the right, PLM engaged.

To make a safe PLM there are some design requirements and product specification needed from the customer like engagement speed, rollaway distance and maximum slope grade, and there is a couple of parameters to be researched like the mass and weight transfer of the vehicle, final drive ratio, park ratchet wheel and park pawl geometry, and park lock components [12]. The ratchet wheel and pawl must be constructed so that when engaged the system is self-ejecting, this means that when the park position is disengaged the reaction force on the pawl can’t hold in place and will jump out of the engaged position. This is to prevent to get stuck when parked on a slope after disengaging the park position. In engaged position the combination of pawl, cone and sliding block will self-lock the system. This will result in a large torque from the ratchet wheel and will make the cone even harder to disengage [13].

1.8.1 PAWL

The pawl in the park lock mechanism is the one thing that locks up the transmission. It is designed as an arm with a tooth on the end. There is also a chamfer on the opposite side of the tooth that will slide against the cone to engage the park lock. A spring is fitted to the pawl to prevent it to engage when it should be disengaged e.g. driving on a bumpy road that makes the pawl rotates up and down.

1.8.2 RATCHET WHEEL

The ratchet wheel is a notched wheel that is fasten on one of the output shafts. The pawl will engage when the tooth fits in one of the notches and therefor lock the output shaft.

1.8.3 SPRING ACTUATOR

The spring actuator is the part that pushes the pawl into engaged mode or disengaged mode. It uses a pin, spring and a cone to do this. The spring must be able to push the pawl into engagement even when the vehicle is rolling. In the case when the pawl is engaged on a tooth, the spring actuator will still continue with the full movement but the cone will be pushed against the pawl without movement until the ratchet wheel will turn to a notch.

2 THEORY

Section 2 will derive all the equations that will be used in the CAE tool. It will describe how the forces acting on the vehicle will affect the PLM.

2.1 FORCES

Force can be described as a push or a pull. A force has a magnitude and a direction.

2.1.1 CAR

The elements that effects the dynamic forces of a vehicle are the mass of the vehicle, m_v, and the acceleration, $d\upsilon(t)/dt$, which is the result of the traction force, F_t, the aerodynamic friction, F_a, the rolling resistance, F_r, the gravitational force on the slope, F_g, and other disturbance forces, F_d, included in Equation 1, see Figure 4.

Equation 1

$$m_v \frac{d}{dt}\upsilon(t) = F_t(t) - \left(F_a(t) + F_r(t) + F_g(t) + F_d(t)\right)$$

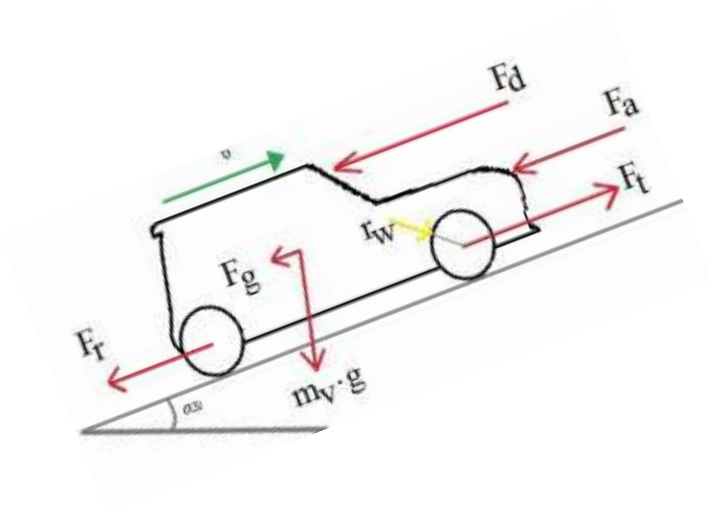

Figure 4. Schematic figure of reaction forces acting on a vehicle while in motion.

When the vehicle is standing still on a flat surface it is normal to the gravitational force. The gravitational force is acting on the vehicle, but reaction force from the surface prevent the vehicle from falling through the surface. When the vehicle is located on a gradient, the reaction force acting on the vehicle will result in an acceleration parallel with the slope due to the gravitational force and the normal forces from the surface, see Figure 5.

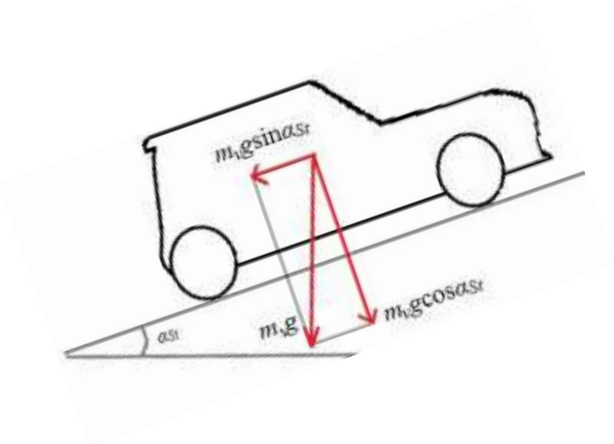

Figure 5. Reaction forces on a vehicle that stands on a slope.

The reaction force $m_v g\sin\alpha_{St}$, will propel the vehicle down the slope if there isn't anything stopping it. So when the vehicle has its parking lock system engaged, the wheels will be locked resulting in, that the frictional force reacting on the tires of the vehicle will keep it in place. The frictional force, F_f, works perpendicular to the normal force, F_n, of the vehicle and the CoF, μ, as described in Equation 2. The PLM stops the vehicle form rolling, resulting in the force holding the vehicle, F_g, from the mass of the vehicle, m_v, gravitational acceleration, g, and the angle of the slope, α_{St}, see Equation 3.

Equation 2

$$F_f \leq \mu F_n$$

Equation 3

$$F_g = m_v g \sin(\alpha_{St})$$

The friction force, F_f, on the tires will cause a torque, τ_w, on the wheel which will be transferred through the drive shafts, differential, final drive gear ratio, R, and last to the park ratchet wheel that will have the counter torque, τ_r, because of the reaction force from the park pawl, see Figure 6.

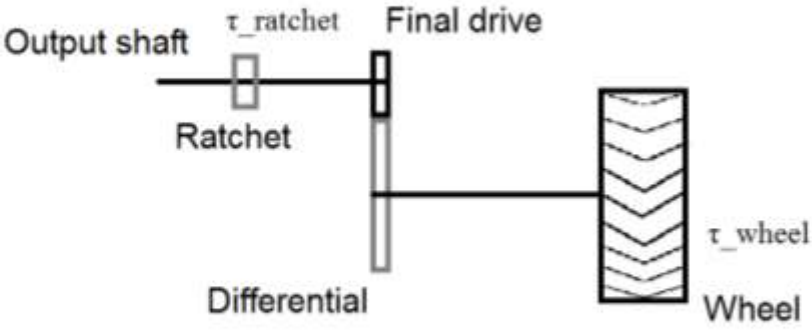

Figure 6. Schematic figure over the torque transfer from wheels to ratchet wheel.

The minimum static coefficient of friction, μ_s, needed without any sliding can be decided by the angle, α_{St} of which the object is not sliding when located on a gradient, see Equation 4.

Equation 4

$$\tan \alpha_{St} = \mu_S$$

2.1.2 RATCHET WHEEL

The ratchet wheel is the notched wheel that is fastened on the output shaft. This wheel needs to take up all the torque and force caused by the vehicle. The ratchet wheel doesn’t necessarily need to be symmetrical due to the geometry and placement of the pawl, see Figure 7. This mean that they can have different angles on each side of the tooth. This geometry will make the pawl self-disengage when the cone has left engage position. The size of the ratchet wheel, numbers of teeth and width of the tooth on the ratchet wheel and pawl will decide the angular movement on the output shaft which in turn will determine the rollback of the vehicle. The angle on the tooth will determine the normal force acting on the tooth. Friction will act on the ratchet wheel and the pawl when the pawl is engaged to one of the ratchet wheel notches. The surface roughness, if too rough or fine, can also contribute to the friction.

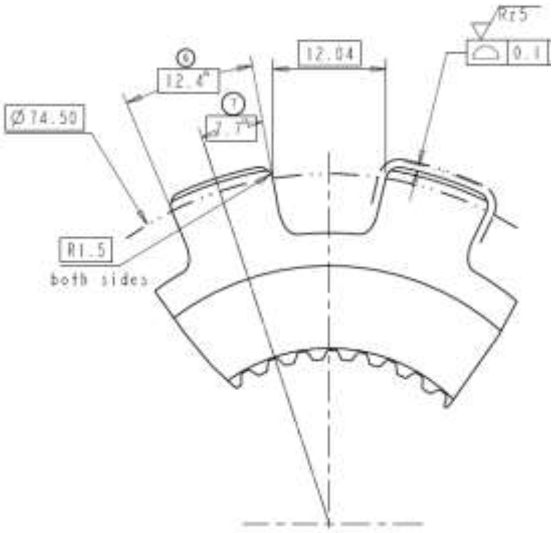

Figure 7. The angles on the tooth of the ratchet wheel show the non symetrical geometry.

2.1.3 PAWL

The placement and geometry of the pawl is essential due to the way the pawl is going to take up the force coming from the ratchet wheel.

2.2 TORQUE

The measure of a force's tendency to produce torsion or rotation about an axis, equal to the product of the force vector and the radius of the vector from the axis of rotation to point of application of the force; the moment of a force.

2.2.1 STATIC

Static torque will affect the parking pawl and the ratchet wheel when the vehicle is standing still. The vehicle in a slope will cause torque to the wheels and will affect the park lock mechanism when engaged with a static torque.

2.2.1.1 WHEEL

The friction force, F_f, needed to hold the vehicle static is the product of the mass of the vehicle, m_v, gravitational acceleration, g, the angle of the slope, α_{St}. The friction force, F_f, and the radius of the wheel, r_w, that acts as a lever will create the torque, τ_w, around the centre of the wheel, see Equation 5 and Figure 8.

Equation 5

$$\tau_w = F_f \times r_w = m_v g \sin\alpha_{St} \times r_w$$

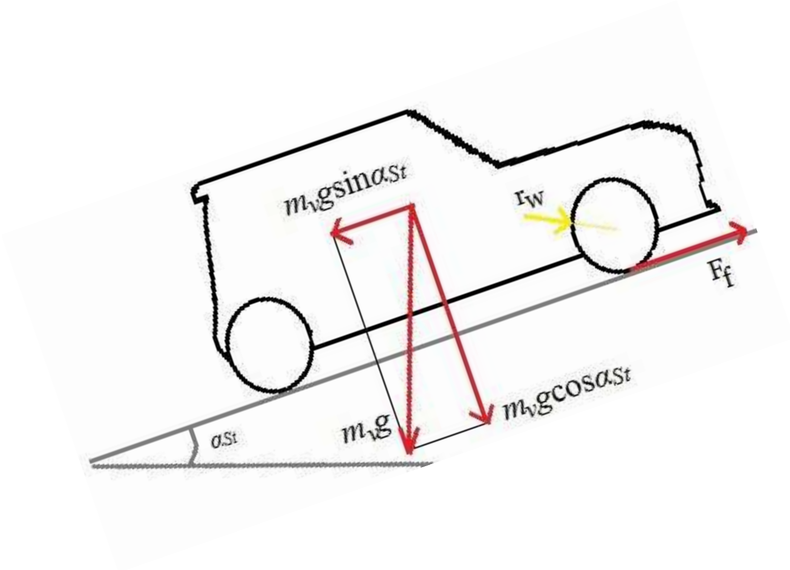

Figure 8. Torque acting on the wheel.

2.2.1.2 RATCHET WHEEL

The torque from the wheel, τ_w, is transferred to the park ratchet wheel. Between the ratchet wheel and the wheel is a differential that has a gear ratio, R. Equation 6 calculate the torque on the ratchet wheel, τ_r.

Equation 6

$$\tau_r = \frac{\tau_w}{R}$$

2.2.2 DYNAMIC TORQUE

Dynamic torque is the needed torque to get a full stop of the vehicle when the vehicle is traveling at a certain velocity.

2.2.2.1 WHEEL

Dynamic torque will act on the wheel, $\tau_{dyn,wheel}$, when the vehicle travels in a chosen velocity, υ, and the PLM is engaged. The force to stop the vehicle is the friction force, F_f, between the tires and the road. The system in Figure 9 shows that the gravitational force, $m_v g$, contributes to the normal forces, F_{N1} and F_{N2}. Only F_{N2} contributes to the frictional force, F_f. The frictional force for a static case must be equal or less than the normal force, F_{N2}, times the static CoF, μ_s, between the tire and the surface. The force, F_f, needed to stop the vehicle depends on the time from when the pawl is engaged to when the vehicle has come to a full stop. The time is known from tests. The dynamic torque acting on the wheel, $\tau_{dyn,wheel}$, is calculated by the mass of the vehicle, m_v, braking acceleration which is the initial velocity, υ_0, final velocity, υ, time for braking, $t_{braking}$, and the radius of the wheel, r_w, by Equation 7.

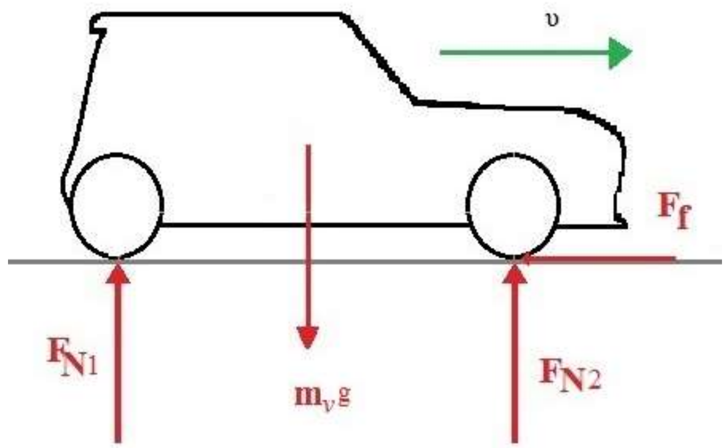

Figure 9. Schematic image of vehicle stopping.

Equation 7

$$\tau_{dyn,wheel} = F_f r_w = m_v \frac{v - v_0}{t_{braking}} r_w$$

2.2.2.2 RATCHET WHEEL

Dynamic torque will act on the ratchet wheel if the vehicle is moving and the PLM is engaged. The pawl will stop the rotation of the ratchet wheel and therefore stop the rotation of the wheels on the vehicle. The torque transferred from the wheel of the vehicle to the ratchet wheel is shown in Equation 6.

2.2.3 SNAP TORQUE

Snap torque, also called snap releases torque, occurs when the vehicle is parked on a slope and the PLM is disengaged and engaged directly after each other to make the vehicle move what is equivalent to one tooth passing on the ratchet wheel. This will make the vehicle accelerate down the slope and gain a certain speed before the PLM stops the vehicle. The system for snap torque is shown in Figure 10. The braking force is the sum of the force from the slope and the friction. The friction acceleration will act on the wheel, $a_{friction}$, due to the braking acceleration, $a_{braking}$, and the acceleration from the slope, a_{St}, see Equation 8.

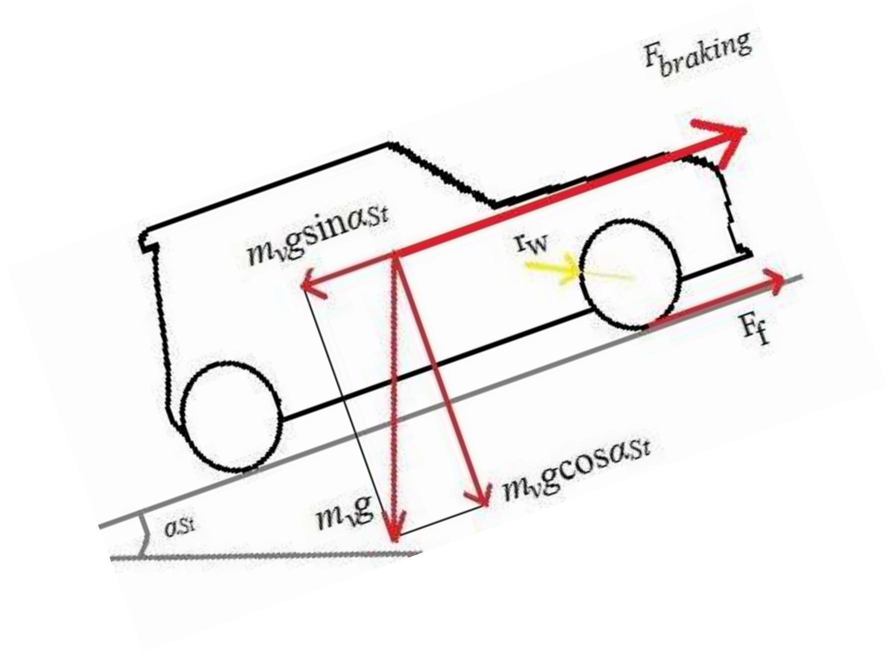

Figure 10. Forces acting on the vehicle when snap case.

Equation 8

$$m_v a_{braking} = m_v a_{friction} - m_v g \sin\alpha_{St} \Rightarrow a_{friction} = a_{braking} + a_{St}$$

The acceleration of braking is calculated by knowing the velocity, v, which is zero in this case, initial velocity, v_0, and time for braking, $t_{braking}$, which is known from real life tests, see Equation 9. The initial velocity, v_0, is calculated by constant energy. For constant energy the acceleration from the slope, a_{St}, and the maximum distance the vehicle can travel before the pawl stops the rotation of the ratchet wheel, $d_{max,wheel}$, see Equation 10.

Equation 9

$$a_{braking} = \frac{v - v_0}{t_{braking}}$$

Equation 10

$$v_0 = \sqrt{2 a_{St} d_{\max,wheel}}$$

The distance, $d_{max,wheel}$, is the product of how long the vehicle has travelled when the ratchet wheel passes one tooth and the number of teeth is known on the ratchet wheel, n, see Equation 11.

Equation 11

$$d_{\max,wheel} = r_w \frac{360^\circ / n}{R} \frac{\pi}{180^\circ}$$

The torque on the ratchet wheel for the snap case, $\tau_{snap,ratchet}$, is calculated by the mass of the vehicle, m_v, friction acceleration, $a_{friction}$, radius of the wheel, r_w, and the final drive gear ratio, R, see Equation 12.

Equation 12

$$\tau_{snap,ratchet} = \frac{m_v a_{friction} r_w}{R}$$

2.3 FRICTION

The friction is the resistance force that resists an object's motion relative over another surface. There are two main frictions; static friction and dynamic friction. Static friction occurs when there is no relative motion between the surfaces and dynamic friction is when two surfaces is relative moving on each other. The coefficient of friction is the fraction that shows the relation between the friction force and the normal force [14].

2.3.1 SURFACE ROUGHNESS

The surface roughness is important for the details that will be sliding against each other.

There are different ways of calculating the surface roughness. R_a and R_z are two ways to calculate surface roughness. R_a is calculated by knowing the height of the peaks on the surface, *z(x)*, and the length on which the peaks are measured over, *L*, and R_z is a function of the average of height of peaks, $R_{1\text{-}5}$, and the average of depth of valleys, $R_{6\text{-}10}$, see Equation 13 and Equation 14. The difference between R_a and R_Z is that R_a is calculated by the measurements of the average length between the valleys and peaks and then divided from the mean line on the whole surface. This makes R_a averages out all the valleys and peaks of the roughness profile and neutralizes some of the few points that is extreme and therefore not have such big impact in the final results. The R_Z value is a calculation of measurements of the vertical distance from the highest peak to lowest valley within five sampling lengths, then averaging these distances. Because of that R_Z only uses five highest and lowest values have a bigger impact on the values of R_Z [15]. High values of the surface roughness on the contact surfaces can result in high CoF which can cause self-locking of the PLM.

Equation 13

$$R_Z = \frac{R_1 + R_2 + R_3 + R_4 + R_5}{5} - \frac{R_6 + R_7 + R_8 + R_9 + R_{10}}{5}$$

Equation 14

$$R_a = \frac{1}{L}\int_0^L \left|z(x)\right| dx$$

2.3.1.1 THE CONSEQUENCES OF ADHESION THEORY

Adhesion theory of friction constitutes of interatomic forces that act over atomic contact spots. These forces, called adhesion, are causing the material to be sheared upon the relative movement between the surfaces. This is still hard to detect because there will be almost no noticeable adhesion e.g. between metals. Adhesion acts during sliding contact between surfaces and at the same time shear is acting. The shear helps to expose clean metal at the top most surfaces. This in which it provides much higher adhesive forces. To measure the adhesive force, the applied normal force must be relieved. During the unloading, the surfaces are decompressed as the elastic tension around the contact spots where the contact bridges are to be deformed to that point that the bridges breaks. When the load is completely relieved, remains only a few small contact bridges. These bridges will barely have any measurable adhesion, see Figure 11.

There are exceptions, where one can measure a significant adhesion. Clean metal surfaces for adhesion significantly during high vacuum conditions. For extremely soft materials (where the elastic relaxation is relatively very small) one can get measurable adhesion by squeezing on to do a little twisting motion to remove surface oxide from the contact patches. There are also cases where one gets a strong adhesion after vibration contact under dry conditions. It is even possible to join the metals by deliberately exposing them to extremely high contact pressure and high sliding speed [14]. The wear on the different part is worth calculating for lifetime calculations. This thesis will calculate during ideal cases and will neglect wear by adhesion in the calculations for the CAE tool. Wear by adhesion is worth mention for the high forces on small contact points on the different parts on the PLM.

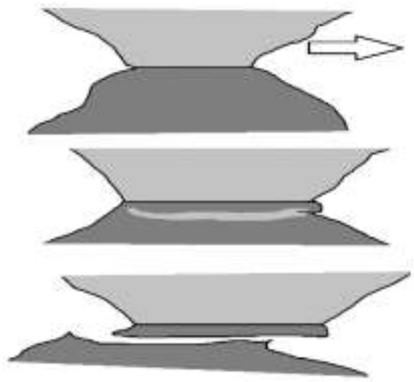

Figure 11. Schematic figure of wear at sliding contact where adhesive contact bridges are broken through shear fractures in one of the materials. Typically too heavy (usually non-lubricated) wear of the metal.

2.3.1.2 THE PLOUGH COMPONENT IN FRICTION FOR ROUGH SURFACES

The friction is independent of the topography for the plough component. For small variations around the typical, reasonably smooth surface roughness, experiments show that this kind of friction applies very well. As a rule, the friction varies little between polished, rough polished and machined surfaces.

For slightly rougher surfaces this can make a significant contribution to the friction of the force required for the harder material's surface peaks must plough through the softer material. This is evident for example in the case of sandpaper against metal. The coefficient of friction for the ploughing component μ_p (Equation 15) receives a supplement equal to the deformation work tips are doing when they plough forward in the softer material. It's common to adopt that abrasive coefficient of friction μ_a and μ_p are independent, Equation 16, and also common adopt that μ_a is independent of the geometry of the peaks.

A static load is the resistance to plastic deformation in the direction of the normal force. This is by definition equal to the hardness H. Dynamic load can, as an approximation to apply the resistance to plastic deformation, be equal to the hardness, H, in both normal force-, F_N, and plough direction. The force on a ploughed, F_p, tip becomes H (which has tension) multiplied by the area of ploughing, A_p, and area from above, A_{lb}, over which they appear to calculate the CoF from the ploughing, μ_p, see Equation 15 and Figure 12 [14]. This thesis assumes ideal cases and neglects wear by ploughing in the calculations for the CAE tool. Wear by ploughing is worth mention for the high forces on small contact points on the different parts on the PLM.

Equation 15

$$\mu_p = \frac{F_p}{F_N} = \frac{A_p H}{A_{lb} H} = \frac{A_p}{A_{lb}}$$

Equation 16

$$\mu = \mu_a + \mu_p$$

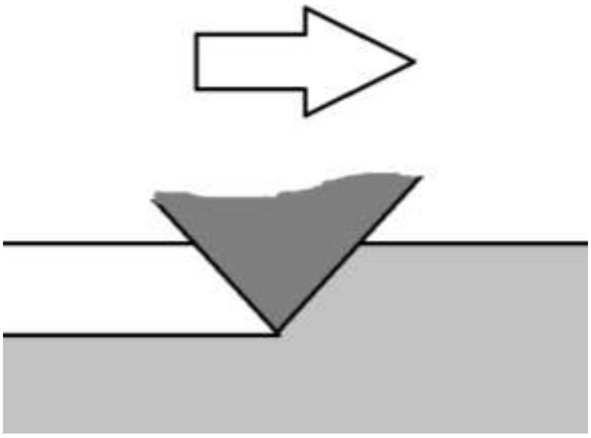

Figure 12. Schematic figure of ploughing.

2.3.2 WEAR

Wear in sliding contact may occur when a solid surface sliding against another. This load may cause numerous surface damage mechanisms. Sliding contact occurs in almost all types of mechanical structures and machine elements, such as cone slides on pawl, pawl rotates on shaft and tooth to tooth contact.

Sliding motion between the surfaces result in abrasive and erosive wear, but differs in that the damage caused by hard particles or surface peaks.

2.3.2.1 CONTACT

There will be a few different tribological systems working on the park lock mechanism. The different systems are shown in Figure 13. In a tribological system, there are some parameters to keep in mind when letting the surfaces slide against each other like the coefficient of friction, surface roughness, oxide films, hardness, lubrication, and wear.

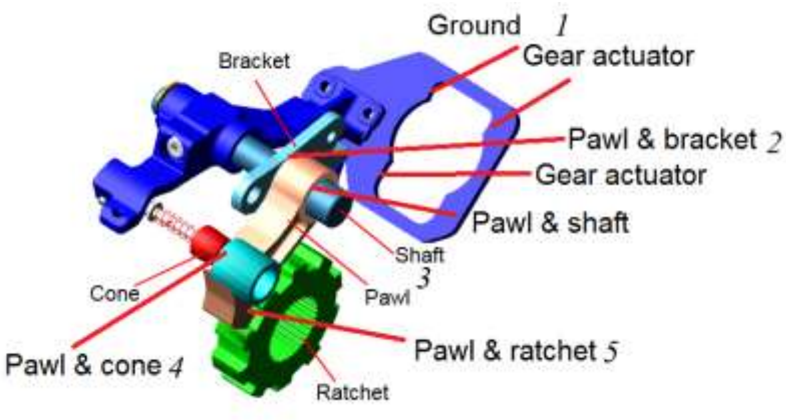

Figure 13. The park lock mechanism with tribological system pointed out, (1) gear actuator & ground, (2) pawl & bracket, (3) pawl & shaft, (4) pawl & cone and (5) pawl & ratchet wheel.

The transmission oil will keep the PLM lubricated and keep both CoF and wear down. The cone will slide against both the pawl and the guide block. This can cause the oxide film to break. Adhesive wear can occur by bare metal contact from the breaking of the oxide film. This can be solved by fast oxide film growth materials. High hardness of the material will provide lower wear [14].

2.5 ENGAGEMENT SPEED

The spring preload is needed to calculate the required force to push the pawl into engaged position when the vehicle is moving in a certain speed. There is an interval for the speed of the vehicle, it’s between the vehicle is parked on a slope and parking pawl will hit the teeth of the ratchet wheel. The maximum the ratchet wheel can rotate before the pawl will stop the vehicle is 360° through the number of teeth on the ratchet wheel, see Equation 18. This will result in a certain distance of travel before the vehicle will stop. This distance and the acceleration down the hill will be a result of a certain velocity just before the pawl will stop the vehicle, see Figure 2. Also a maximum speed is required so that the transmission doesn’t break when the parking pawl is engaged. Over a certain velocity the parking pawl will start ratcheting if it’s engaged over this velocity. The angular velocity on the ratchet wheel resulting from the vehicle is the bench mark.

The acceleration down the slope is calculated by Equation 17.

Equation 17

$$a_{st} = g\sin(\alpha_{St})$$

The maximum the ratchet wheel can rotate, $\theta_{max,ratchet}$, before the pawl will stop the vehicle is 360° through the number of teeth on the ratchet wheel, n, see Equation 18.

Equation 18

$$\theta_{\max,ratchet} = \frac{360^{\circ}}{n}$$

The calculation for roll away in degrees on the wheel for the vehicle, see Equation 19.

Equation 19

$$\theta_{\max,wheel} = \theta_{\max,ratchet} / R$$

The distance the vehicle will travel during roll away is calculated by Equation 20.

Equation 20

$$d_{\max,wheel} = \theta_{\max,wheel} \cdot r_w \frac{\pi}{180^{\circ}}$$

The maximum velocity the vehicle will gain during snap release case is calculated by Equation 21.

Equation 21

$$\upsilon_{\max,snap} - \upsilon_0 = \sqrt{2 a_{st} d_{\max,wheel}}, \upsilon_0 = 0$$

The maximum angular velocity for the wheel during the dynamic case when the vehicle is traveling the velocity which is set for the dynamic case is calculated by Equation 22.

Equation 22

$$\omega_{Wheel} = \frac{\upsilon_{\max,dyn}}{r_w} \left[rads / s\right]$$

The maximum angular velocity for the ratchet wheel is calculated by Equation 23.

Equation 23

$$\omega_{ratchet} = \omega_{wheel} R, \left[rads / s\right]$$

The time span, t_{open}, when it's clear for the parking pawl to jump into position is calculated by knowing the angular velocity of the ratchet, $\omega_{ratchet}$, and the angle the vehicle can move when the pawl is engaged, $\theta_{uphill,downhill}$, see Equation 24. The average angular acceleration for the pawl to jump into parking position, α_{pawl}, is calculated by the time span, t_{open}, and the radians the pawl needs to travel for full engagement, $\theta_{engaged,pawl}$, see Equation 25. This calculated spring force is the lowest force needed to get the pawl engaged while the vehicle is traveling in at a certain speed. The equation is similar to the pull out force as will be explained at section 2.6 PULL OUT FORCE, only the direction of the friction is changed.

Equation 24

$$t_{open} = \frac{\omega_{ratchet}}{2\pi} \frac{\theta_{uphill,downhill}}{360^{\circ}}$$

Equation 25

$$\alpha_{pawl} = \frac{2 \cdot \theta_{engaged,pawl}}{t_{open}^2}$$

From the angular acceleration, the actual force needed from the cone, $F_{cone,y}$, is calculated by the return spring torque, $\tau_{r,s}$, moment of inertia for the pawl, I_{pawl}, angular acceleration of the pawl, α_{pawl}, and the distance from the rotation point of the pawl to the contact point between the pawl and cone, $d_{pawl,cone}$, Equation 26. This equation includes the return spring that is mounted in the vehicle.

Equation 26

$$F_{cone,y} = \frac{\tau_{r,s} + I_{pawl}\alpha_{pawl}}{d_{pawl,cone}}$$

The average force needed from the actuator spring, $F_{avg,actuator,spring}$, is calculated by the force from the cone, $F_{cone,y}$, the average angle of the cone which comes from the length of movement of the cone, x_{tot}, and the lift the cone has made from the engagement, y_{tot}, and CoF between pawl and cone, $\mu_{pawl,cone}$, Equation 27.

Equation 27

$$F_{avg,actuator,spring} = 2\frac{F_{cone,y}}{\cos\left(\tan^{-1}\left(\frac{y_{tot}}{2x_{tot}}\right)\right)}\left(\mu_{pawl,cone}\cos\left(\tan^{-1}\left(\frac{y_{tot}}{2x_{tot}}\right)\right)+\sin\left(\tan^{-1}\left(\frac{y_{tot}}{2x_{tot}}\right)\right)\right)$$

2.5.1 CONE

When the fork, see Figure 1, move horizontal, the cone will lift the actuator to an angle. The cone will also lift the pawl to an angle. The total lift of the pawl, y_{tot}, is calculated by knowing the length of movement, x_1, the cone makes while on the lifting angle of the cone, θ_{lift}, the length of movement, x_2, during the locking angle of the cone, θ_{lock}, see Equation 28, see Figure 14. The total length of travel for the cone is the lengths x_1 and x_2 added to each other.

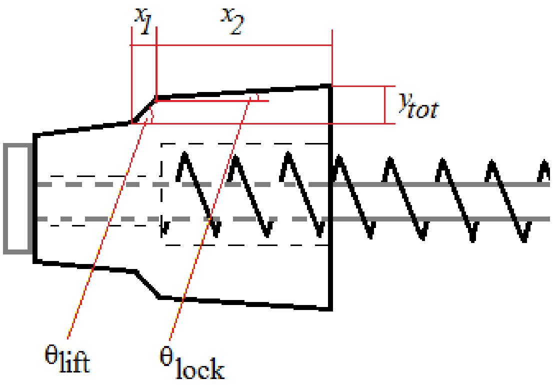

Figure 14. Drawing of the cone.

Equation 28

$$y_{tot} = 2\left(x_1 \tan\theta_{lift} + x_2 \tan\theta_{lock}\right)$$

2.6 PULL OUT FORCE

Pull out force is the required force to disengage the park lock mechanism. The cone will be sliding against the guide block and the pawl. This will cause friction, see Figure 15. The coefficient of friction is important so that the park lock mechanism doesn't self-disengage. The lowest coefficient of friction that the system needs to not self-disengage is $\tan\theta_{lock}=\mu_{pawl,cone}$ due to the angle between the cone and the pawl/guide block. A way of controlling the static CoF is to put the part on a plane that can be tilted gradually until the part begins to slide. The angle of which the part begin to slide is the static CoF [14].

The force, $F_{pullout}$, needed to disengage the PLM is the force from the pawl, F_p, locking angle, θ_{lock}, and the CoF between the pawl and cone, $\mu_{pawl,cone}$, see Equation 30. The force from the pawl, F_p, is a product of the torque from the ratchet wheel, τ_r, distance from rotation point of pawl to the tangential force acting from ratchet wheel, $d_{F,r}$, radius on the ratchet wheel, $r_{ratchet}$, and the distance from rotation point of pawl to the contact point between the pawl and the cone, $d_{pawl,cone}$, see Equation 29. Higher torque on the ratchet wheel will increase the frictional force so it becomes harder to disengage. This friction force can't be higher than what the gear actuator can produce.

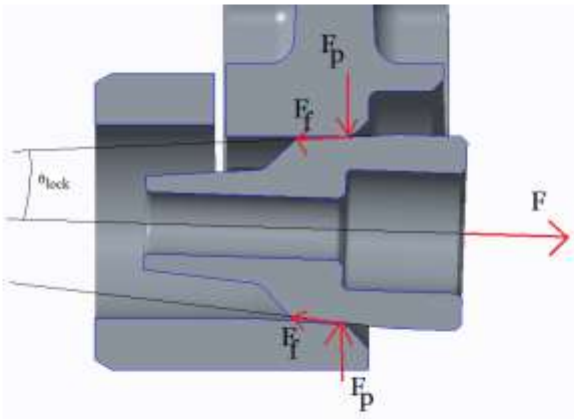

Figure 15. Cross-section figure of the friction force on the pawl (on the top), cone (in the middle) and guide block (on the bottom).

Equation 29

$$F_p = \frac{\tau_r d_{F,r}}{r_{ratchet} d_{pawl,cone}}$$

Equation 30

$$F_{pullout} = 2F_p \cos\theta_{\text{lock}} \left(\mu_{pawl,cone} \cos\theta_{\text{lock}} - \sin\theta_{\text{lock}}\right)$$

2.7 RETURN SPRING

The return spring keeps the pawl from self-engaging due to accelerations acting on the vehicle e.g. driving over bumps or potholes. The torque needed from the return spring, $\tau_{r,s}$, is calculated by the inertia of the pawl, I_{pawl}, maximum acceleration, $a_{max,g}$, angle of the pawl, θ_{tan}, acting on the pawl and distance from the rotational point of pawl to its centre of gravity, $d_{pawl,CoG}$, see Equation 31 and the system is shown in Figure 16.

Equation 31

$$\tau_{r,s} = \frac{I_{pawl} a_{\max,g} \cos\theta_{\tan}}{d_{pawl,CoG}}$$

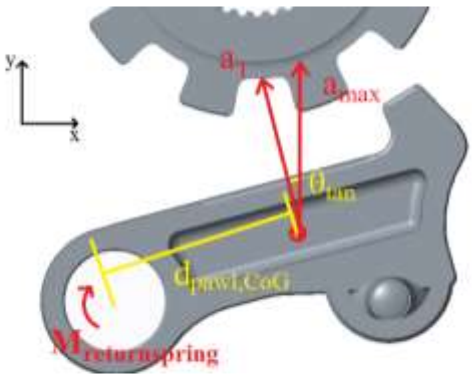

Figure 16. The system exposed by an acceleration.

3 RESULT

The result is a CAE tool in form of an Excel workbook that will calculate:

- Static torque on ratchet wheel on a slope with or without trailer.
- Dynamic torque on ratchet wheel on 0% grade with or without trailer.
- Snap release torque on ratchet wheel on a slope.
- Friction limits between pawl and cone.
- Pull out force, uphill and downhill.
- Engagement speed.
- Rollback.
- Release spring.
- Actuator spring.

The inputs needed for the calculations:

- Mass of vehicle.
- Mass of wheel.
- Mass of pawl.
- Mass of trailer.
- Radius of tire.
- Radius of pawl contact point downhill.
- Radius of pawl contact point uphill.
- Radius of pawl centre of gravity.
- Radius of pawl centre of cone.
- Radius of the ratchet wheel.
- Lever for force on pawl from static force from the ratchet wheel.
- Gear ratio on final drive.
- Gravitational acceleration.
- Slope gradient.
- Number of teeth on ratchet wheel.
- CoF between pawl and cone.
- Coefficient of rolling resistance.
- Angle of the cone locking.
- Angle of the cone lifting.
- Angle of the pawl traveling from disengaged to engaged.
- Angle of the ratchet wheel traveling from uphill to downhill.
- Angle of the pawl to the horizontal line.
- Angle of pawl travelling before hitting the ratchet wheel tooth.
- Angle of release spring preloaded.
- Angle of release spring engaged.

- Distance travelled by the fork.
- Maximum g's acting on pawl.
- Maximum pull out force from gear actuator.
- Preload on cone actuator.
- Armed load on cone actuator.
- Torque preloaded release spring.
- Torque engaged release spring.
- Velocity for dynamic torque.
- Length of actuator spring preloaded.
- Length of actuator spring armed.
- Lumped stiffness of drive shaft.

A user manual was made for the CAE tool. The user manual describes parameters with figures for better understanding over what kind of values that are needed for the calculations. The user manual will also tell the user how to use the CAE tool in a correct way to get the desired values.

3.1 DESIGN

The CAE tool was created using an Excel VBA workbook.

The first sheet consists of all the result the user can gain. The user can pick the required vehicle with the correct specifications and thereafter get the wanted results. The dropdown list has different vehicles with different specifications to choose between. The selected vehicle will take all input data from the "inputdata" sheet into "sheet5" where all values has been defined. The user clicks on the button on which calculation that should be done and will be given an answer in the output table. The buttons for calculations is copied from the calculation sheet, "sheet2" and pasted in the output table. There are some input data that can be found on the first sheet that doesn't have anything to do with the vehicle but to the different cases like the angle on the slope, maximum dynamic velocity, maximum g's, and braking time, see Figure 17.

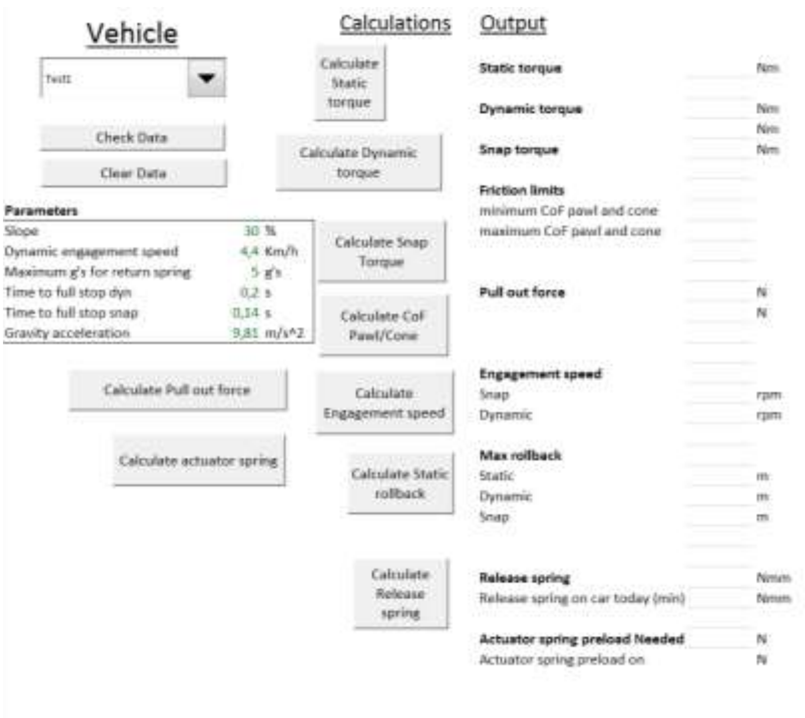

Figure 17. Sheet 1 on the workbook of the CAE tool.

In the square under parameters in Figure 17, the user can find the standard parameter which has nothing to do with the vehicles. Values that can be found in this box is the gradient on the slope in percentage, the velocity of the vehicle when calculating on the dynamic case, maximum amount of g's that will affect the pawl to calculate the return spring, the time during the braking for the dynamic and snap case and also the gravitational acceleration.

The gray boxes in Figure 17, if the user clicks on these buttons, different actions will take place. All buttons that starts with the word "calculations" will copy the specific answer that the user requires and be pasted under the output header. The button "Check Data" will make a control check of the input data of the selected vehicle. Things that for example is checked is the mass of the vehicle doesn't exceed 4 536kg. The "Clear Data" will erase all the output values on "Sheet1".

On the sheet "Sheet2", are all the calculations done. This sheet has all the equations and is made by defining all input values so that the correct value goes in the correct equation, see Figure 18. The user can find specific calculations that can be required of the user. For example, torque on the wheels will not be shown on "Sheet1", if the user has to know what kind of torque the wheels will be exposed to for simulations on the wheels, the user can find this value on "Sheet2".

Calculations					
Static torque					
Force on the slope	F_θ	4735,723032	N		
Torque on wheel	t_w	1548,344645	Nm		
torque on ratchet	t_r	496,2643094	Nm		
Dynamic torque					
acceleration of braking	a_braking_dyn	6,111111111	m/s^2		
angular acceleration	aa_braking_dy	27,14059096	rad/s^2		
torque on wheel	t_dyn_w	4874,064419	Nm		
torque on ratchet with slope	t_dyn_r	1562,200134	Nm	@	30 %
Torque on ratchet without slope		1075,861111	Nm	@	0 %
Snap torque					
Max rotation on ratchet	θ_max,ratchet	30	°		
Max rotation	θ_max,wheel	9,615384615	°		
Max rollaway static	d_max,rollawa	0,054868788	mm		
Force dynamic		4641,008572	N		
Force Rolling resistance	F_rr	94,71446065	N		
acceleration "snap"	a_snap	2,762505102	m/s^2		
Velocity of car when snap	v_car	0,550591151	m/s	1,982128	km/h
kinetic energy		254,6465171	J		
acceleration breking	a_snap_braking	3,932793936	m/s^2		
angular acceleration	aa_snap_braki	12,02873203	rad/s^2		
Torque on wheel	t_snap_wheel	3677,567075	Nm		
torque on ratchet	t_snap_ratchet	1178,707396	Nm		
Friction limits					
Least CoF between cone and paw	CoF	0,052407779			
Pull out force					

Figure 18. Sheet 2 has all the equations and calculations.

The sheet "inputdata" is for storing all the input information about the vehicles. Here the user can fill in new vehicles and give them new values. This is where the dropdown list from the first sheet gets all the information, see Figure 19. Values that will be needed is listed in 3 RESULT. The values in Figure 19 are made up and are not from real vehicles.

		mass of vehicle	Trailer mass (kg	mass wheel (kg	mass pawl (kg)	Gear ratio	Rim size (")	Tier width (mm	Tier hight (%)	wheel radi
1	Test1	2450	1816	22	0,223	3,435	17	250	56,84	[illegible]
2	Test2	2000	1816	22	0,223	3,435	18	240	35	[illegible]
3	Test3	1816	1816	22	0,223	3,25	18	225	45	[illegible]
4	Test4	2060	1816	22	0,2	3,12	21	185	30	[illegible]
5	Test5	1680	1816	22	0,2	3,12	16	225	55	[illegible]
6	Test6	2500	1816	22	0,15	3,12	20	250	35	[illegible]
7	Test7	2630	1816	22	0,15	3,54	20	250	35	[illegible]
8	Test9	2225	1816	22	0,15	3,5	20	250	35	[illegible]
9										0

Figure 19. Sheet inputdata gather all the technical specification about the vehicle.

The last sheet is the input sheet. On this sheet, all the values are defined. The dropdown list on the first sheet picks a vehicle and that vehicles input information is put in this sheet. So that the values can be defined and be used in the equations, see Figure 20.

Input		
	2	
Vehicle:	Test1	
m_v	2000	kg
Mass trailer	1816	kg
mass wheel	22	kg
m_pawl	0,223	kg
R_v40	3,435	
Rim size	18	"
Tier width	240	mm
Tier height	55	%
Radius on tier	0,3606	mm
Numbers of teeth	10	
c_r	0,02	
S_pawl,up	74	mm
d_ratchet,down	74,65	mm
d_ratchet,up	74,65	mm
s_F_r	14,2205	mm
s_F_r_uphill	11,78	mm
µ_p_c	0,1	
Lumped stiffness	737	Nm/rad
Engagement speed		
Length preloaded (L1)	39,5	mm
Length Armed (L2)	30,5	mm
preloaded force, L1	34,2	N
Armed force L2	44,4	N
rotation pawl	6,3537	°
r_prickadlinje	37,325	mm
	0,037325	m
θ_downtouphill	3,34234	°
moving the fork		
x_1	2,75	mm
x_2	6,25	mm
x_tot	9	mm

Figure 20. All values from the chosen vehicle are defined.

4 DISCUSSION

4.1 GENERAL DISCUSSION

When comparing the values from the CAE tool to the values from previous reports [16, 17] that other companies have done they aren't always the same. The values between the companies can also vary which indicates that they use different equations or neglect some values e.g. the dynamic torque case when both Vicura and PUNCH has the same input the result differs by 0,4%. For the calculations on the preload force needed from the actuator spring the values differs by 34% between Vicura and the CAE tool.

The actuator rod in this design will be tilted 2° when engaged due to the cone that slides against the guiding block making the locking angle slight different from the calculated case. This makes the locking angle on the pawl side 2° less and 2° more on the guide block side. This will not affect the pull out force much because of what it loses in friction force on the guide block it gains on the pawl side. The CAE tool doesn't consider this problem. The two CoF must be summed up and the average of them will show the CoF needed as minimum.

Equation 32

$$\mu \geq \frac{\tan\theta_1 + \tan\theta_2}{2} \approx \tan\frac{\theta_1 + \theta_2}{2}$$

The torque on the ratchet wheel is a product of friction force between the road and the tire, lever as the radius of the tire and the gear ratio. The friction force that contributes to the torque on the wheels is never calculated with the normal force times the coefficient of friction. It is instead calculated with the needed force to stop the vehicle in a certain time to get the worst load case. The CAE tool will often give a higher torque value than the values that will come from test results. The conditions on the road when the vehicle has been tested can change, all from dirt on the road, bad tires and different weight distribution of the vehicle. The stopping time that is used in the calculations is taken from these tests and may not give an accurate results from an ideal case. The stopping time from test result can also differs if the vehicle is going uphill or downhill. For example, the vehicle has the PLM on the front wheels and the vehicle is facing downhill, it will stop sooner than uphill. The tires slides more when the vehicle rolling back when uphill. This can be due to the suspension of the vehicle. The suspension is neglected in the CAE tool and is calculated as a stiff box. When the vehicle got suspension, the rotational momentum of the vehicle will be downhill and will increase the normal force on the wheels downhill and if the vehicle has the PLM on that side the ratchet wheel will experience more torque due to increase friction force and less sliding.

All the calculations are done with a hundred percentage of efficiency in the system (ideal case). There is some losses in the transmission like between gears in form of sound, vibrations and heat. There is also no slip between the tire and the surface in the calculations. In tests with the nose uphill and the snap release case, the vehicle usually slips for a couple of centimetre before coming to a full stop. Therefore, the time for the braking acceleration used in the calculations, is not always correct.

4.2 DESIGN DISCUSSION

The tool will calculate the torque for the static, dynamic and snap case for any kind of vehicle with an automatic transmission, because the torque is calculated to the output shaft which the PLM is located and has nothing to do with the design the PLM. The friction limits calculation consider the angle of which locks the pawl in to engaged mode. The friction then depends on the angle and the tool would only calculate the friction if there is a locking angle involved. There may be some design on a PLM that doesn't use a locking angle and have another solution to the problem.

The engagement speed can be implemented on every vehicle with the DCT. This calculates the angular velocity of the ratchet wheel when the maximum velocity of the vehicle is reached and it still will be able to get the pawl into engage mode. The rollback calculation apply for most vehicle with a DCT. The rollback calculations depends on the design of the ratchet wheel, final drive gear ratio and the tire radius. This solution is common among the DCT vehicles. There can be other solutions to lock the wheel and there can still be rollback, the user must therefore define the way it is designed to calculate the rollback using the tool. The release spring is only able to be calculated if the pawl is rotated. The release spring is a torsion spring and will give torque to the pawl to not jump into engaged position if the vehicle will be exposed of acceleration, like going over a pothole. The same accounts for the actuator spring. This design must be a straight spring with a cone that has a lifting angle, a locking angle so that the pawl can be lifted and locked safely without fail to fit the CAE tool.

The CAE tool has a lot of assumptions and simplifications to make the tool more universal. The CAE tool doesn't consider if the construction has a loose fit, therefore consideration has to be done when making real time tests and also when designing the part. The cone and the actuator rod is one example of loose fit. This can increase the friction force between the two parts and load the rod with high contact forces. This case mostly happens when the pawl shall disengage when the cone has a lot of force on it.

The calculations using the dimension of the cone is restricted to the design of the cone. The cone used in the tool has two angles and two lengths. If a new design is taken, the equation must be changed to consider the new design.

The calculation of the actuator spring is calculated by average force and acceleration. In the real case the acceleration of the pawl take place in two parts. First is the part when the cone is lifting the pawl with the lifting angle of the cone, double the distance in y-direction than the cone is moving the cone in x-direction and second part is the locking angle of the cone which lifts the pawl only a little. This makes the acceleration on the pawl high in the beginning and after the lifting angle a smaller acceleration.

The acceleration on the pawl is calculated into one tangential force, see Figure 21, but in real case the force will look more like the force is in the y-direction all the time. This will make a small error on the actuator spring calculation. But because of that the pawl is only moving ~6,5°, the correction is neglected.

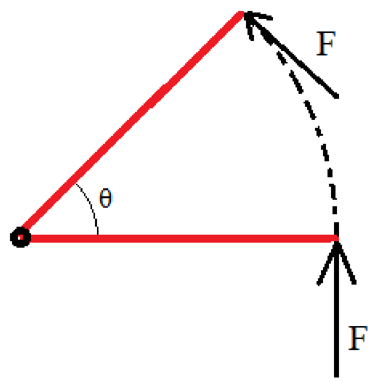

Figure 21. Tangential force action on a rotational arm.

The friction between the pawl and the cone when the cone is engaging the pawl is neglected due to its small contribution for the actuator spring calculation. The CoF is small to begin with, it's between 0,08 to 0,18, and this is for a wet gear box [17]. The normal force on the cone is whatever the pawl is contributing with and it's some of the weight of the pawl and the return spring. This will not give a significant value to the actuator spring.

The value for the actuator spring is the mean amount of force the spring must execute. The spring force changes with the compression with the spring. The user can use the value as the preload but if the spring coefficient is known a smaller compression can be used and still execute the engagement of the pawl.

4.3 FUTURE WORK

The CAE tool could have more functions and equations to make it a handier tool. The tool should include weight distribution for more exact values like them form a real life test. The tool should also consider the condition of the road because of that the torque on the wheel comes from the friction force between the road and the tire of the vehicle. If the user can choose the tire that is used and on what kind of surface it will be tested on, the results would be more accurate.

More work can be done on the design of this tool to make it easier to use for anyone and to understand how it works.

If the tool could import data directly from CAD files to get input data for the calculations, it would be a major help for the tool to work smooth and fast.

Because of that the pawl should always jump out of parked position when the PLM is disengaged, there should be a function in the tool that tells the user that it will for sure do that. There should also be calculations of torque on the pawl acting while it has torque on it from the ratchet wheel. There can be different values on the CoF between the pawl and the ratchet wheel making the friction force differ. If the CoF would be too high or wrongly designed the pawl could get stuck when high loads acting on the pawl. This must not happen.

5 CONCLUSION

According to the goal which is described in section 1.4, the goal was to create a CAE tool that would give values on the requested output values for different designs and other specifications on the vehicle.

The method used for the CAE tool was Excel VBA and the design can be found in section 3.1 DESIGN

The needed input data and the calculated output data was defined in section 3 RESULT. All the equations for calculate the output data is found under the section 2 THEORY.

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7 APPENDICES

7.1 LIST OF FIGURES