

Efficiency and safety strategy of a CK2 with Nissan controller

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**Efficiency and Safety strategy
Of a CK2 with Nissan controller**

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DCT 2004 82

Eindhoven, July 6 2004

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1 Introduction

At the Technical University of Eindhoven (TU/e) there is a test rig for a CK2 continuously variable transmission. The goal of this rig is to apply realistic road loads and effects of inertia to a CVT and then try different control-strategies in order to improve the performance of the gearbox. For these tests there first must be a control measurement to determine the performance of the standard controller, so after a new control-strategy is tested it can be compared with the original situation and determine if the new strategy is better or worse than the old one and of course how much better or worse.

First the way the CVT works will be examined. Followed by the rig (TR3-rig) itself. After that a number of experiments are to be done. The efficiency, torque-loss and safety strategy of the CVT will be determined. This will be followed by the conclusions that can be drawn from the results.

2 The Continuously Variable Transmission *

2.1 The gearbox

The CVT is a type of gearbox with an unlimited number of gear ratios, hence the word continuously, which also implies the following characteristic, namely that it can continuously change the gearratio without disrupting the powerflow from engine to wheels like the clutch does in combination with a manual gearbox. The CVT works using two pulleys. Each pulley consists of a set of two conical discs between which a pushbelt runs. By applying different pressure levels to one half of the pulley the distance between the two halves can be changed, the closer the two are together the bigger the radius at which the belt runs becomes. If on the primary pulley the pressure is increased and the belt will be

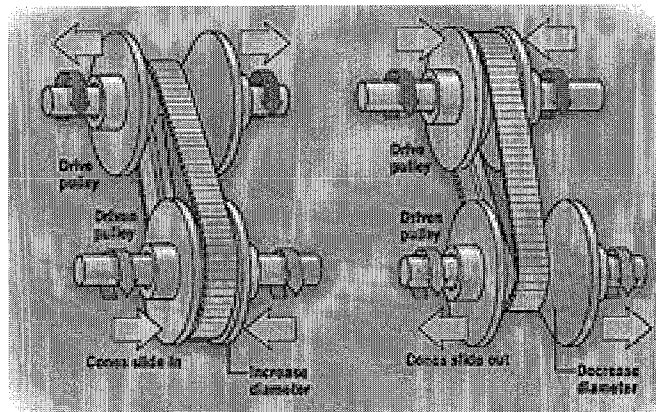


Figure 1: Pushbelt and pulleys of a cvt

pushed further up on the pulley and because of this it will automatically be pulled down between the secondary pulley. When the pressure on the primary pulley is lowered the belt will relax a little and the secondary pulley will tension it by forcing it up to a bigger radius. The oil pressure in the gearbox is build up by a build in gearpump. Behind the pushbelt and pulleys a final set of gears is placed to lower the speed a little further to the desired level.

2.2 The torque converter

When starting and stopping the slip between the still turning engine and the standing wheels has to be compensated. The compensation cannot be done by the CVT because slip will ruin the belt. For this reason there is a torqueconverter installed between the engine and the gearbox. The turbine side of the torqueconverter is coupled to the flywheel of the engine so it turns at the same speed as the crankshaft. The fins on the inside of the pump part (also rotating at the same speed as the flywheel) produce an oil

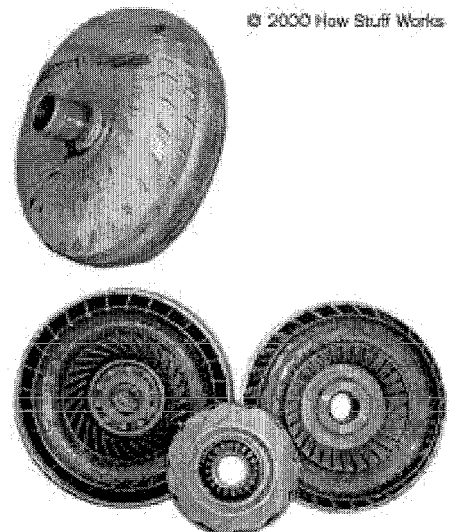


Figure 2: Torque converter assembled (above) (below from left to right) turbine, stator, pump.

* For further information on the cvt: Harold Peeters (2001)

flow. This oil flow is guided through the fins of the turbine that turns independent from the housing and is coupled to the ingoing axle of the transmission. The stator in the middle is coupled to the transmission housing with a one direction coupling so the stator can only turn in the opposite direction of the pump. The job of the stator is to reverse the flow direction of the oil after it leaves the turbine so it flows into the pump in the right direction. The stator also amplifies the torque when the pump is turning faster than the turbine. When the car is running at a constant speed the torqueconverter still slips a little because the energy losses of the oil on its way from the pump to the turbine cause a speed difference between the two. At constant speeds this is not necessary, this means that the torque converter wastes energy. To prevent this the torque converter has a lock up, this means the pump and turbine can be locked to each other so slip becomes impossible and no more energy will be wasted.

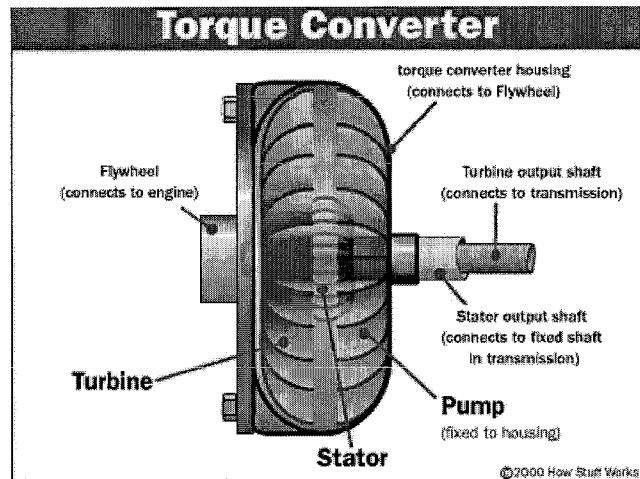


Figure 3: Working of a torque converter

2.3 The DNR-set

Because a car has to be able to reverse and stand still in neutral a Drive-Neutral-Reverse-set (DNR-set) is mounted between the torqueconverter and the variator part of the gearbox (the pulleys and pushbelt). This set allows the engine to run entirely disconnected from the gearbox (neutral mode) and also to go to normal drive or reverse mode. This is done using a planetary system because in this way the set can be constructed relatively small and the ingoing axle can stay in one line, it is only interrupted by the DNR-set. For the different drive modes, different parts of the planetary set have to be fixed, this happens by hydraulic brakes attached to the different components of the set. The pressure for these brakes comes from the same pump as the pressure used for putting pressure the pulleys.

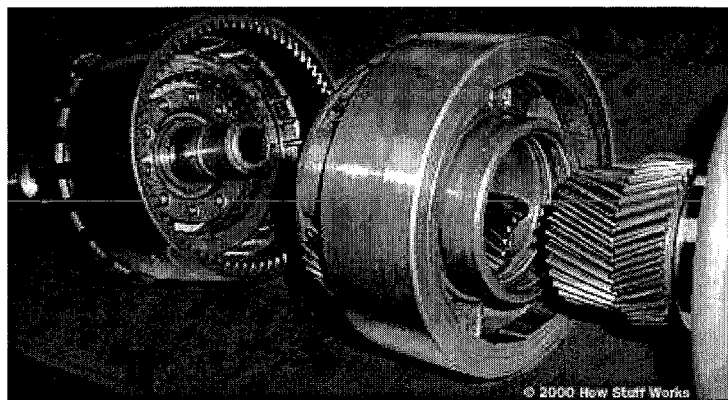


Figure 4: Planetary gear set, from left to right, outer ring, planet carrier and double sun wheel

3 The TR3 Test Rig*

The rig used to test the CK2 gearbox is an old test rig of Van Doorne's Transmissie. This rig is equipped to simulate vehicle mass by using a flywheel. Because the gearbox and engine have to accelerate this mass the inertia of this wheel simulates the mass of the car. Road loads are simulated using a current brake. Which is a large electric motor that applies torque to propeller shaft of the rig in the opposite direction of the motor torque applied to this shaft. The current brake can be set to simulate the braking torque a car experiences from the air resistance and also the torque an incline can induce on a car.

The whole rig was adapted because the control systems for the brake and the mounted engine were obsolete. The engine and gearbox that are mounted on the rig came from a wrecked Nissan Primera that still had a good engine. The engine is a 2.0 liter petrol engine that is couples to a CK2 continuously variable transmission. The transmission has a manual mode with six fixed ratios and a Low setting for extreme inclines or heavy loads. The drive shafts of the Primera are coupled to a propeller shaft using a gearbox on each side. These gear boxes have fixed ratio of about 1:1.7. This means the propeller shaft turns faster than the drive shafts. The advantage this provides is that a lighter flywheel can be used because at greater speeds its moment of inertia becomes bigger.

One the rig different things can be measured:

- Ingoing Torque: between the torqueconverter and the engine a spacer is placed in which a Torque measuring shaft is placed. On this shaft strain gauges are placed which are supplied with energy and read out through a telemetry system.
- Outgoing Torque: is also measured with strain gauges, but these are placed on the drive shaft on the right side of the gearbox.
- Rotation speed in and outgoing: The rotation speed of the gearbox is measured on the primary and secondary pulley, this is done using the Hall sensors Nissan put in there.
- Engine speed: this is measured using the standard revcounter coupled to the computer.
- Pressure sensors: sensors are put in to measure the pressure on the primary and secondary pulley and there is also on to measure the line pressure.
- Temperature sensors: a sensor is placed in the oil of the CVT to measure its operating temperature.
- Engine temperature: is measured through the standard sensors build in by Nissan.

For the oil from the engine and gearbox and for the cooling fluid of the engine, three different cooling systems are installed. The engine oil and cooling fluid temperatures are controlled by the engine itself and the temperature of the

* For further information on the TR3: Making the TR3 available for practical (2003)

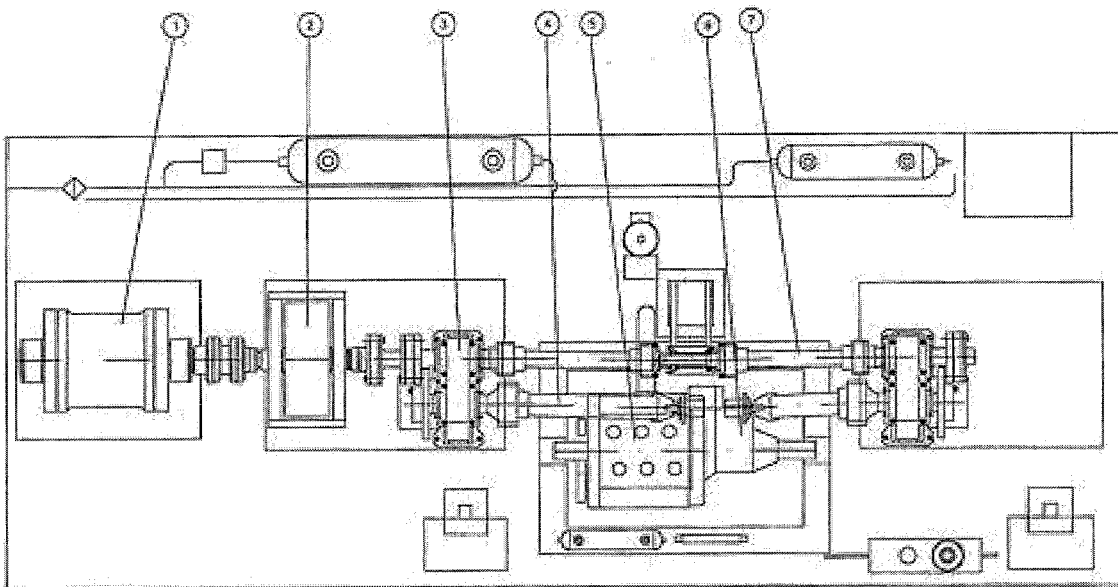


Figure 5: The TR3 test stand, 1= current brake, 2 = flywheel, 3 = gearbox, 4 = drive shaft, 5 = internal combustion engine, 6 = continuously variable transmission, 7 = propeller shaft.

gearbox is controlled by the computer so it can be set at different temperatures to examine the performance of the gearbox at different temperatures.

The test rig is controlled with a computer using a simulink model combined with a D-space system. It is possible to set the throttle valve of the engine using a stepper motor. By adapting the simulink it is also possible to control the engine speed. The current brake can be controlled in two different ways. The first option is to control the brake torque it supplies and the second option is to set the break to a fixed speed.

4 Efficiency and Safety Strategy

4.1 Efficiency

The efficiency of the gearbox can be determined in different ways. The first option is doing it bit by bit, this means first perform measurements on the DNR set and determine its efficiency followed by the pump the variator and the final gears, when these are combined the total efficiency is known. It is not possible to measure all of these components separately because you need to measure in- and outgoing torque and is not possible to measure the torque before and after all the components, there simply is not enough space to mount torque sensors. Thus the only thing that can be measured is the overall efficiency of the CVT. To determine this except for in- and outgoing torque, the in- and outgoing speeds also have to be known. With it is fairly simple to determine the in- and outgoing power by using

$$P = T \cdot \omega$$

then the efficiency is calculated by

$$\eta = \frac{P_{out}}{P_{in}}$$

If the ratio of the variator and final gears is known it is also possible to describe the efficiency by calculating the torque loss over the gearbox. To calculate the Torque loss the outgoing torque first has to be multiplied by the variator ratio and the final gear ratio. This way the loss of torque is visible in comparison to the start amount. The torque loss can then be calculated in the following way

$$T_{outonin} = T_{out} \cdot ratio \cdot \frac{1}{5.474}$$

in which 1/5.474 is the ratio of the final gears in the CVT.

$$T_{loss} = T_{in} - T_{outonin}$$

Because the torque loss increases with increasing ingoing torque this result does not clearly show the efficiency of the gearbox. The efficiency is shown much better when the torque loss is described as a percentage of the ingoing torque.

3.2 Safety strategy

The belt in a CVT has to be clamped between the pulleys so it doesn't slip. To do this pressure is applied to the pulleys. How much pressure is necessary to keep the belt from slipping can be calculated. For these calculations the force needed on the secondary pulley is calculated, because normally the pressure on the primary pulley is not known and depends on the ratio and ratio changing speed. To minimum clamping force needed differs for ratios smaller or equal to 1 and ratios bigger or equal to 1.

For ratios ≤ 1

$$F_{2min} = \left(\frac{\cos \beta}{2\mu} + \frac{1}{e^{\frac{\mu\gamma_1}{\sin \beta}} - 1} \cdot \frac{2\delta}{\tan \beta} \right) \cdot \frac{T_{in}}{R_1}$$

in which β = pulley angle, μ = friction coefficient that lies around 0.09, γ_1 = wrapped angle around the first pulley, δ = variable depending on the ratio and R_1 = the radius at which the pushbelt runs on the first pulley. (For calculating R_1 see appendix A)

For ratios ≥ 1 the equation becomes,

$$F_{2min} = \left(\frac{\cos \beta}{2\mu} \right) \cdot \frac{T_{in}}{R_1}$$

These calculations for the minimum clamping force are however not directly applied in the control of a CVT gearbox. Because the ingoing torque is not exactly known and the friction coefficient always changes because it depends on the running speed of the belt, the condition of the pulley surface that can change and the viscosity changes in the oil when it heats up. Therefore a safety strategy is applied to the pressure control of the CVT. This safety strategy often exists of the formula for the clamping force at ratios greater than 1 multiplied by a safety factor. This factor usually lays around 1.3. This means that the calculated clamping force for ratios smaller than 1 is lower than the real force needed and that the safety factor is a little lower there because of this difference. Tests however show the safety factor is higher for ratios lower than 1 instead of lower. This is probably because the friction coefficient is higher at low ratios and low belt speeds. (J. van Rooij, 2002)

The safetyfactor can be calculated by first determining the real force applied in the gearbox and dividing that by the minimal theoretically needed force.

$$F_{real} = p_{sec} \cdot A$$

A = surface that is pressurized on the secondary pulley, p_{sec} = pressure on the secondary pulley. Then follows the safety factor:

$$\text{Safetyfactor} = \frac{F_{\text{real}}}{F_{2\text{min}}}$$

By calculating the safety factors at different ingoing torques a safety strategy can be discovered. This is done by plotting these factors against the ingoing torque and look if a clear connection between the points can be seen.

5 The Experiments

5.1 Testing on the TR3

To determine the efficiency and safety strategy of the CK2 with a Nissan controller tests have to be done on the TR3. From the results of these test the efficiency will be calculated for different values for the ingoing torque and for different ratios, low (0.43), medium (1.1) and overdrive (2.25). Problem with controlling these settings on the TR3 is that the Nissan controller always shifts up to a high as possible ratio for minimum fuel consumption of the engine. Only in low it would be fairly simple to do the tests because the controller has a fixed low ratio programmed into it. So it would be virtually impossible to set ingoing torque as well as the ratio at the same time. The only way this might be done is by putting a controller on the engine that controls the ingoing torque and then fiddle with the current brake to force the CVT to the desired ratio.

In this way test have to be done at the three given ratios and with an ingoing torque of 20 to 150 Nm with steps op 10 Nm.

5.2 The BTS test rig

Because the torque sensor on the ingoing axle of the TR3 broke down before the tests started and parts to repair it were not received in time for the tests they had to be moved to the BTS-rig. This rig is basically the same as the TR3 except the motor on the ingoing side is an electronic motor instead of an internal combustion engine. The other big difference was that there was no Nissan controller available for this rig. The controller that is installed on this rig has the advantage that ingoing torque and ratio could be set at the click of a button. And by using data gathered from earlier tests with the TR3 the controller could be set to almost the same pressure levels as the ones used by Nissan. (22 bar for low, 14 bar for medium and 7.5 bar for overdrive.) To further simulate the use of an internal combustion engine the ingoing torque is divided in to three groups that are tested at different engine speeds, this is done because the petrol engine cannot deliver 150 Nm at 150 rad/s and 20 Nm at 300 rad/s also is not a realistic situation. So the torques from 20 to 80 Nm are tested at 150 rad/s, 90 to 120 Nm at 250 rad/s, and 130 to 150 Nm at 400 rad/s. (For a precise account of al the test parameters see Appendix B)

6 Results

6.1 The experiments

The experiments as described earlier had to be changed a little when doing the experiments with the low ratio it was not possible to go further than 130 Nm because the slip of the CVT started to rise and almost reached 2 %. The problem is that above 2 % slip the belt can slip away and get damaged. An attempt to raise the pressure level had to be stopped at 28 bar because when the pressure was increased even further the pulley deformed a little so the slip readings become unreliable, so it was not safe to continue. Therefore the experiment was stopped at 130 Nm. When experimenting at medium and overdrive the secondary motor reached its limit of 400 rad/s before the driving motor reached 400 rad/s so these for these tests the speed of the measurements with 130 to 150 Nm were done at 300 rad/s. The last three measurements in overdrive are done using the VDT control strategy for the pressure. This strategy uses a safety factor that can be predetermined by the operator of the rig.

6.2 The efficiency

After the experiments the torque loss and the overall efficiency were calculated as described in paragraph 3.1. The results of these calculation are plotted and shown in the following figures. Figure 6 shows the torque loss at the three ratios.

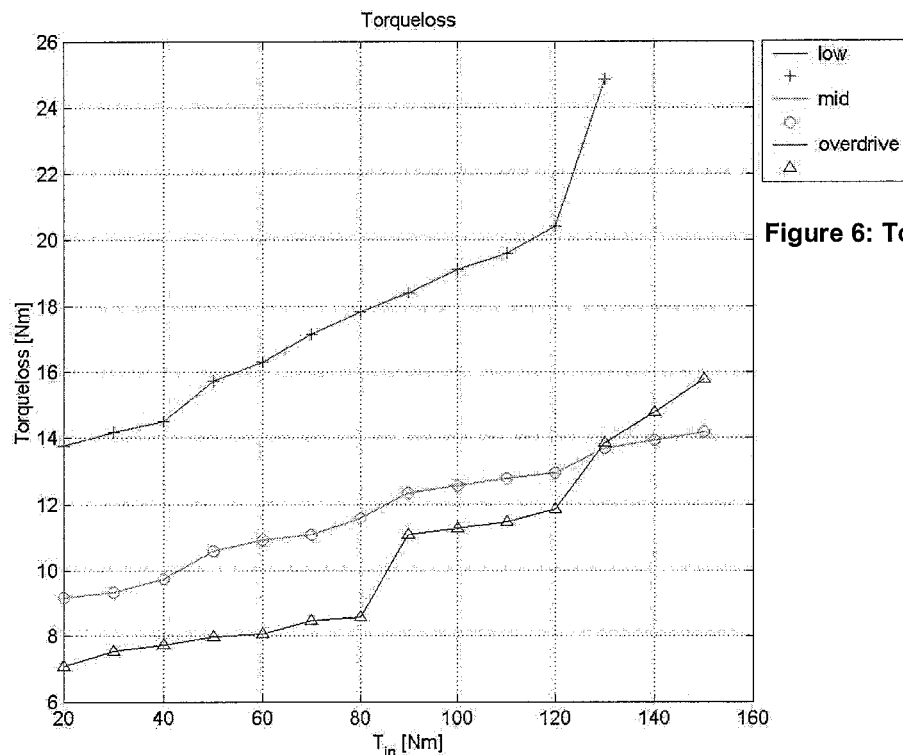


Figure 6: Torque loss

Unexpected is the fact that for most torque levels overdrive is more efficient than medium, because at medium the radii on both pulleys are almost the same so there should be minimum slip with that condition. This difference can only be explained by the fact that the oil pump also contributes to the loss and at overdrive the pressure is only half the pressure at medium so there will be littler losses there. The fact that medium scores better at the last three data points is because of the VDT strategy that is used in overdrive for these measurements and that drove the pressure up a little. The jump the torque loss makes at the end of the plot for low is caused by the increase in pressure from 22 to 28 bar

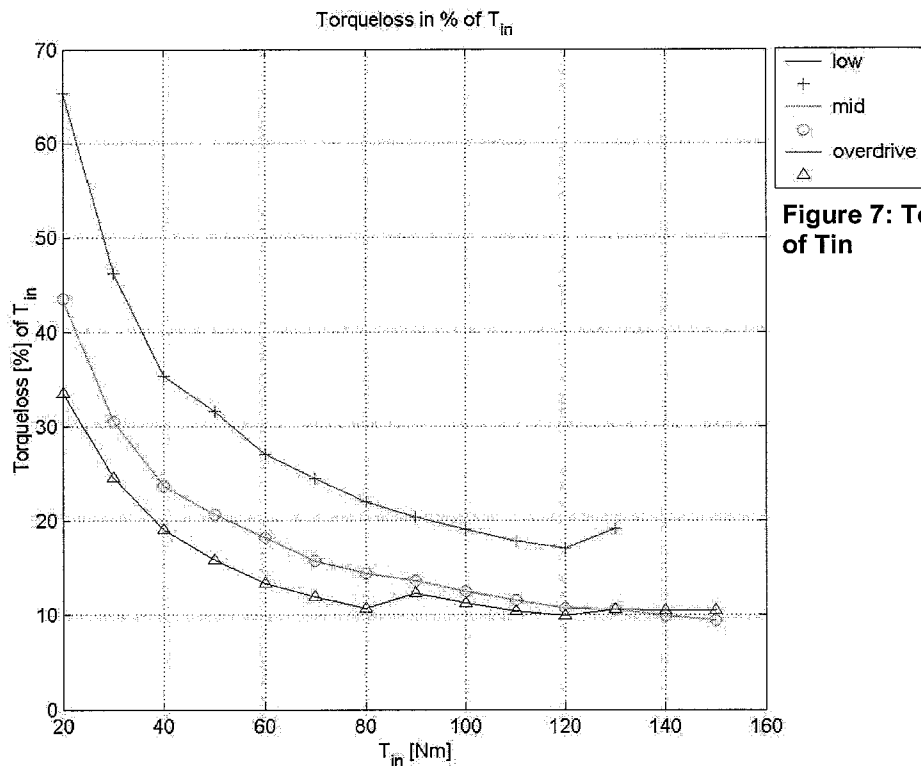


Figure 7: Torque loss in % of T_{in}

that causes an extra loss in the pump. Figure 7 shows that the torque loss relatively decreases with increasing torque. This is probably because the pressure level inside the CVT is constant for low and high torque so at low torque the losses in the pump are the same as at high torque but the torque that is passed on is much lower so relatively more torque will be lost. The torque loss decreases less fast at higher torques, probably because slip is becoming more and more a significant factor. In both plots the line for overdrive makes a jump at 80 Nm this can be explained by the fact that at that point the speed was increased. Strangely however this jump is not visible in the medium and low lines. Figure 8 shows the pressure on the secondary pulley during the experiments. In this plot there is also a clear jump in the overdrive line at 80 Nm that is not there in the other two lines. So the jump is not likely to be caused by the increase in speed because that means it has to be visible in all three lines.

Another explanation can be that the increase in speed has more influence at lower pressures, it could be that at a certain speed the pressure can't drop any lower so when accelerating the pressure rises a little because of the higher speed of the gear in the pump. It is also clearly visible that the VDT strategy lets the pressure rise with the increase of torque. (last three points of the

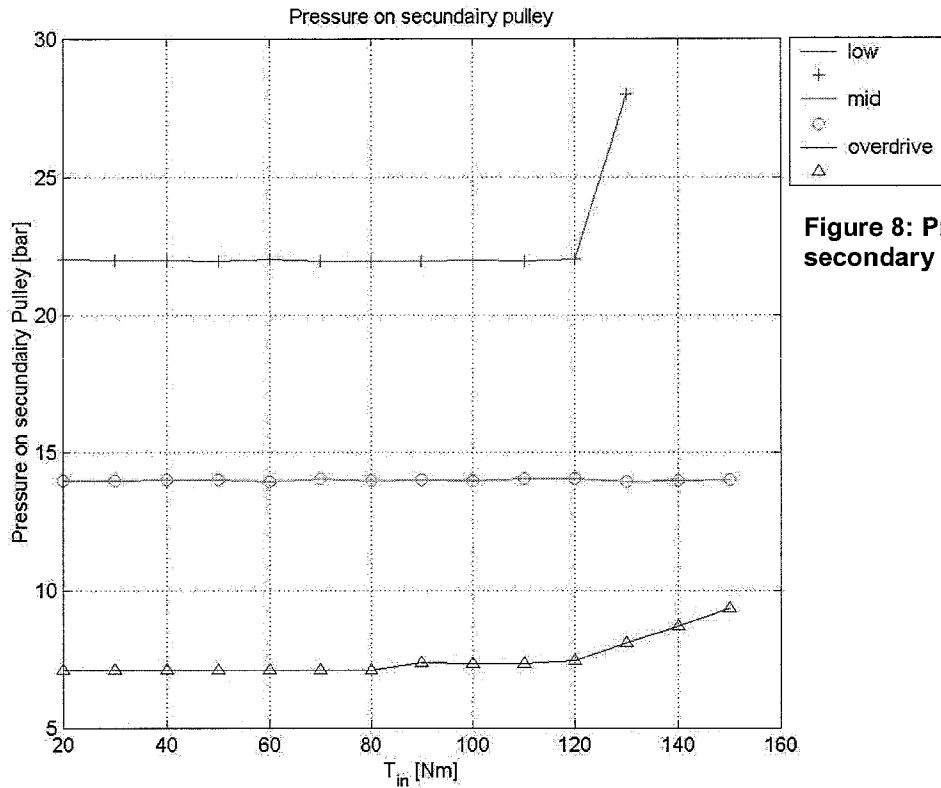


Figure 8: Pressure on the secondary pulley

overdrive line.) Figure 9 shows the efficiency of the CVT. This figure is almost the opposite of figure 7, which is logical because the efficiency depends on the torque and speed before and after the CVT. The loss in torque is a lot higher than the loss in speed. The loss of speed is caused by the slip of the belt. The torque however not only decreases because of the slip but also because of the oil pump and friction in the final gears and bearings. The slip is about 1 % and the rest of the loss can therefore mainly be addressed to the pump losses. So the loss of speed has almost no influence on the total efficiency and therefore the efficiency loss looks like an up-side-down torque loss in % graph.

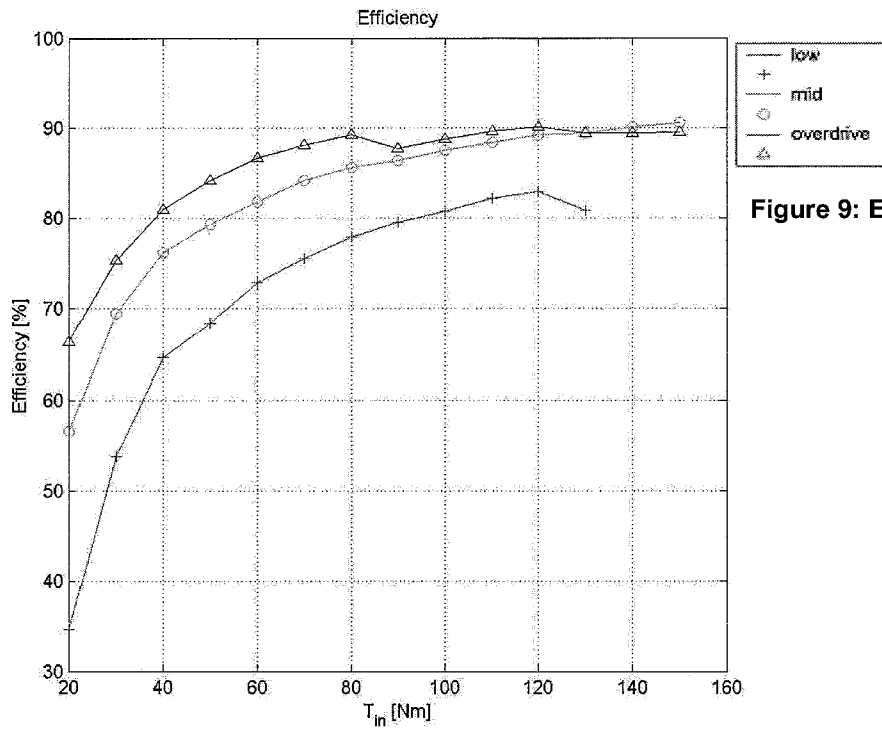


Figure 9: Efficiency

6.3 The safety strategy

The safety factor can be determined as explained in paragraph 3.2. Figure 10 shows the safety factors used by Nissan. In this graph it is clearly shown that

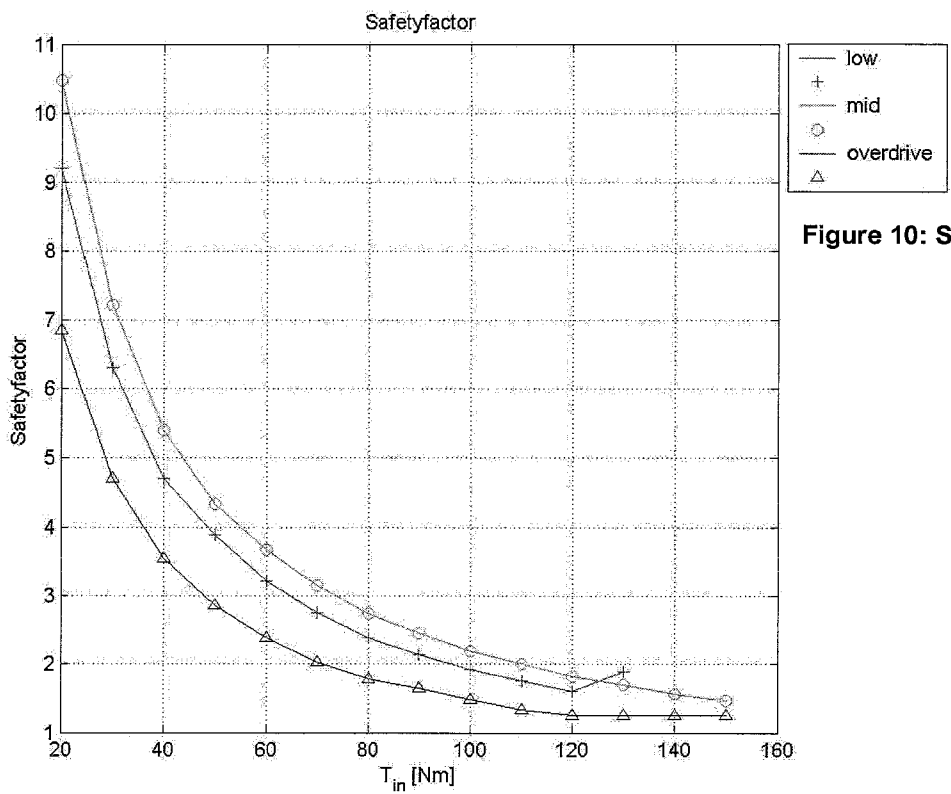


Figure 10: Safety factors

Nissan does not have a clear strategy because the safety factor changes constantly. This can be seen clearly when the medium and low lines are compared to the last three point on the overdrive line, because these three are measured with VDT strategy they are constant at ± 1.3 . The Nissan strategy is clearly different from the strategies that try to predict the minimum pressure and than multiply that value with a certain safety factor. To get a better insight on what Nissan does figure 11 shows the real force against the theoretical minimum for the low ratio. In this figure it is clearly shown that Nissan chooses to apply a pressure that results in a force big enough to keep the belt from slipping even when the maximum torque of 180 Nm is delivered by the engine. By keeping the

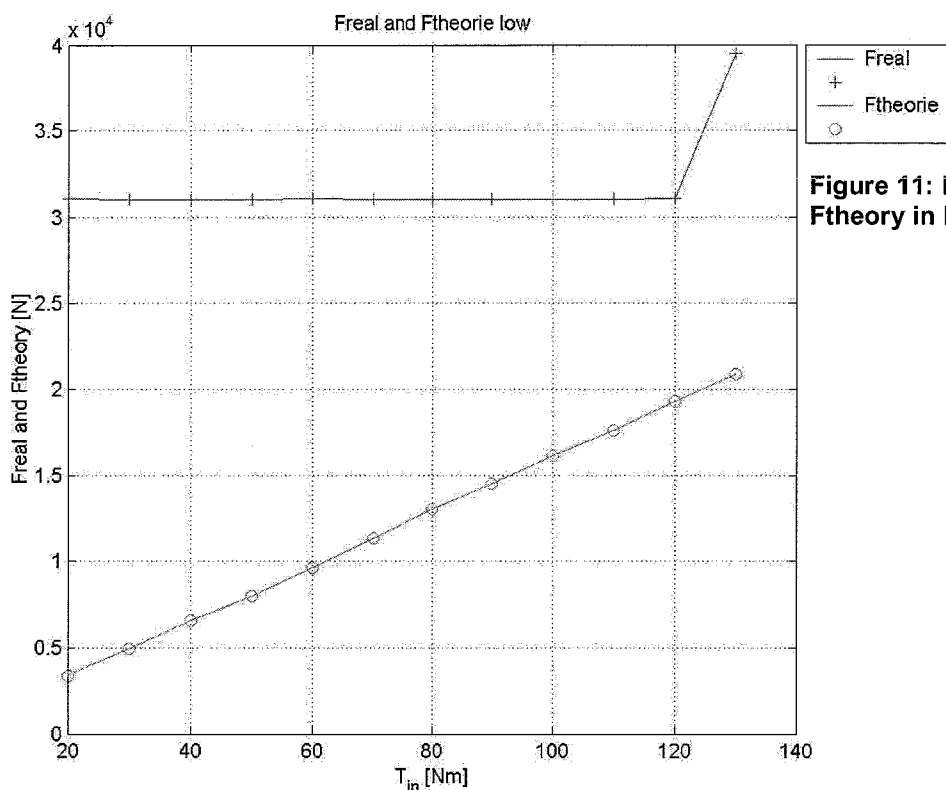


Figure 11: Freal and Ftheory in low

pressure constant Nissan chose for maximum safety. The strategy chosen by Nissan is also shown in figures 12 and 13. In figure 13 it is also clear that VDT uses a safety factor of ± 1.3 because the two lines run almost parallel at the last 3 data points with a space of approximately 0.3 times the theoretical force. The lower margin at the end of the force lines for overdrive might be explained by the fact that the the gearbox in overdrive probably does not have to deal with fast torque changes because the engine is in its best point for efficiency and because of the higher speeds at which overdrive is engaged the engine will not be able to accelerate very fast and if a driver chooses to go full throttle the gearbox will lower the ratio and thus raise the pressure so more torque can be channeled through.

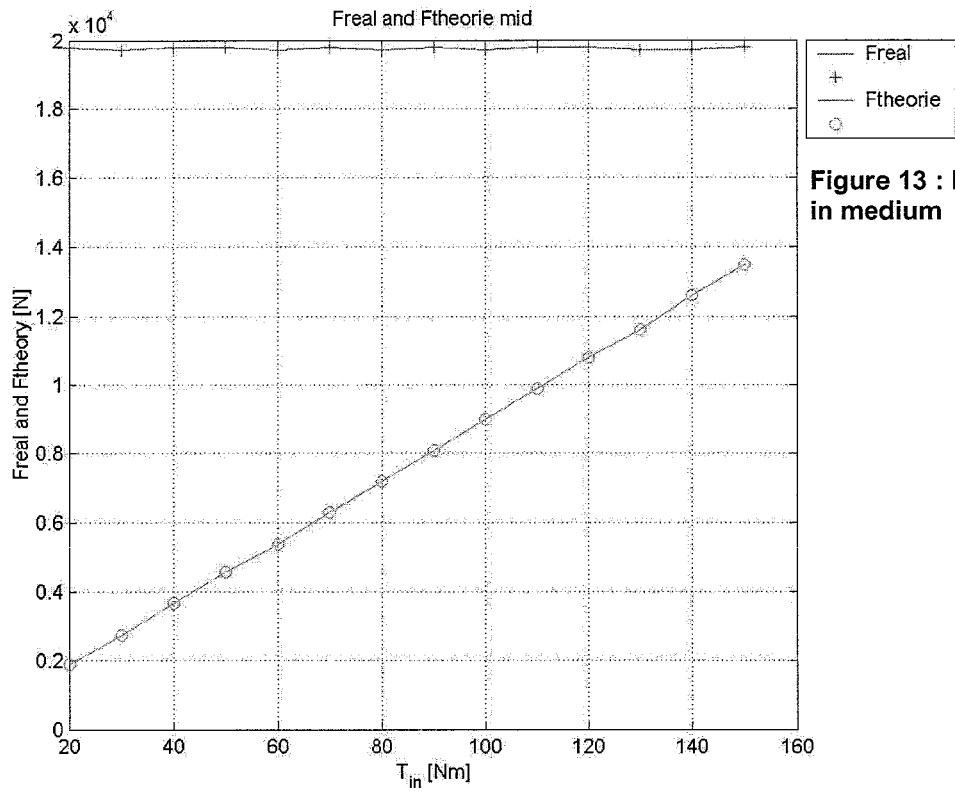


Figure 13 : Freal and Ftheory in medium

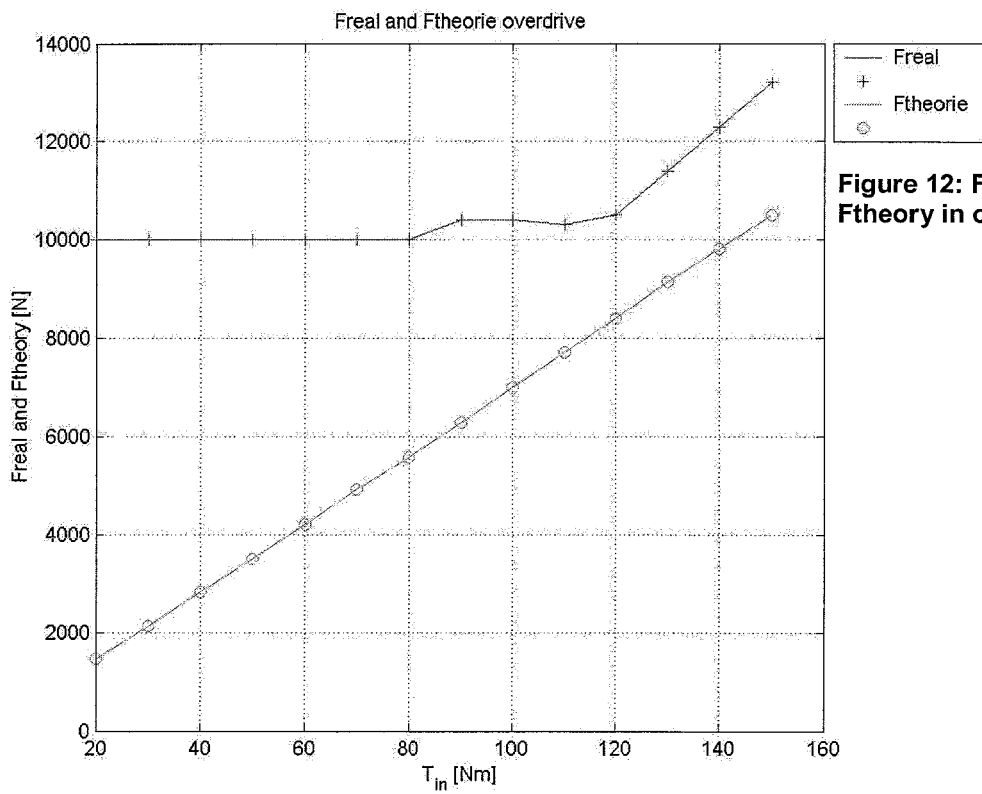


Figure 12: Freal and Ftheory in overdrive

7 Conclusion

After conducting the experiments and analyzing the data it becomes clear that the safety strategy Nissan uses for its CVT is a bad strategy. The reason for this is that they calculated the maximum amount of clamping force needed added on a safety margin and put that on the belt. The problem with this approach is that the maximum amount of torque is not always led through the CVT so there is no use for this large amount of force. Nissans strategy has a great number of disadvantages.

Higher loads will be put on the different parts of the CVT, like the bearings and axles and the belt and pulleys themselves. This means these parts will wear faster which means repairs will be needed much sooner. To counter this, higher quality materials could be used, problem with this is that it makes the gearbox more expensive. And all these measures are not necessary if a smart strategy is chosen. A smart strategy is a strategy that minimizes the safety factor to keep overclamping to its minimum.

Another big disadvantage of overclamping is that more pressure is needed than necessary which means the pump has to work harder and that means it will use more energy. The pump being the most important factor in the efficiency of the gearbox the pressure should be kept low as possible to prevent these losses. So overclamping is bad for the efficiency and bad efficiency is bad for fuel consumption. One of the advantages of the CVT is that the engine is allowed to run at an efficient point and if a part of the fuel saved by this is wasted again on overclamping the use of the CVT is less beneficial.

The only advantage of this extreme form of overclamping is that the belt will not slip and the change of damage because of slip is very limited this way.

So it would be better to use another strategy that uses the minimum amount of overclamping. To reach this goal research on the TR3 can be useful because the behavior of a car is simulated very well, the inertia as well as the road load.

8 Recommendations

Because the tests were done on the BTS rig and without a Nissan controller they basically are not more than a good approximation of the actual tests on the TR3. The conditions of the TR3 are simulated as good as possible, by setting pressures and ratios to values found in earlier measurements. For validation of the tests done it is recommendable to try and do two or three measurements again on the TR3 with original Nissan controller and check if the results are comparable to the results printed here.

The last three measurements in overdrive also should be done again because they are done with VDT strategy this time and that way it is not possible to draw any conclusions from these measurements in relation to the Nissan strategy.

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Symbols

Symbol	Variable	Unit	Unit symbol
P	Power	Watt	W
T	Torque	Newton*meter	Nm
ω	Angular Velocity	Radials per second	Rad/s
η	Efficiency	-	-
μ	Friction factor	-	-
γ	Wrapped angle	degrees	°
β	Pulley angle	degrees	°
δ	Variable dependent on ratio	-	-
F	Force	Newton	N
p	pressure	Bar/Pascal	Bar/Pa
A	Area	Meters ²	m ²
R	Radius	Meter	m

Appendix A: calculation of the radius and variables

function [R1_m]=r2Rp(r_m,Lb,Av);

a = (1./r_m - 1).^2./Av;

b = pi.*(1./r_m + 1);

c = 2.*Av - Lb;

Delta = b.^2 - 4.*a.*c;

Rpri1 = (-b - (Delta).^(1/2))./(2.*a);

Rpri2 = (-b + (Delta).^(1/2))./(2.*a);

R1_m = [Rpri2];

Variables

r_m = ratio

Lb = belt length 702.8e-3 m

Av = distance between axles 168e-3 m

A = 141.13e-4 m²

$\beta = 11^\circ = 2/\pi * (11/360)$ rad/s

$\mu = 0.09$

Appendix B: Test data and conditions

K=[20,30,40,50,60,70,80,90,100,110,120,130,140,150]

Klow=[20,30,40,50,60,70,80,90,100,110,120,130]

verliesvectl=[13.77,14.16,14.50,15.72,16.30,17.15,17.82,18.40,19.10,19.61,20.42,24.84]

verliesvectpercl=[65.41,46.15,35.37,31.65,27.07,24.45,22.06,20.42,19.04,17.83,17.04,19.11]

effl=[34.58,53.84,64.63,68.34,72.88,75.52,77.93,79.56,80.76,82.17,82.97,80.88]

pressecl=[22.03,22.00,21.99,21.97,22.04,21.96,21.96,21.96,21.99,21.97,22.03,27.97]

verliesvectm=[9.18,9.35,9.76,10.61,10.92,11.08,11.59,12.35,12.55,12.79,12.94,13.67,13.92,14.18]

verliesvectpercm=[43.47,30.56,23.75,20.65,18.16,15.74,14.35,13.62,12.44,11.54,10.68,10.55,9.90,9.39]

effm=[56.53,69.45,76.25,79.34,81.84,84.25,85.63,86.37,87.55,88.46,89.31,89.46,90.12,90.59]

pressecm=[14.00,13.97,14.03,14.03,13.96,14.04,13.99,14.03,13.99,14.04,14.04,13.96,13.98,14.03]

verliesvectod=[7.07,7.53,7.74,7.97,8.07,8.46,8.59,11.08,11.27,11.48,11.86,13.84,14.77,15.78]

verliesvectpercod=[33.61,24.61,19.05,15.81,13.31,11.92,10.69,12.25,11.21,10.37,9.85,10.57,10.50,10.47]

effod=[66.39,75.39,80.95,84.19,86.70,88.08,89.31,87.76,88.79,89.62,90.15,89.43,89.49,89.51]

pressecod=[7.11,7.10,7.11,7.10,7.10,7.10,7.10,7.38,7.34,7.33,7.45,8.07,8.69,9.35]

Freall=[3.11e4,3.10e4,3.10e4,3.10e4,3.11e4,3.10e4,3.10e4,3.10e4,3.10e4,3.10e4,3.10e4,3.11e4,3.95e4]

Ftheoriel=[3.38e3,4.92e3,6.60e3,7.98e3,9.65e3,1.13e4,1.30e4,1.45e4,1.61e4,1.76e4,1.93e4,2.09e4]

safetyfactorl=[9.21,6.30,4.71,3.89,3.22,2.75,2.39,2.14,1.92,1.76,1.61,1.89]

Frealm=[1.98e4,1.97e4,1.98e4,1.98e4,1.97e4,1.98e4,1.97e4,1.98e4,1.97e4,1.98e4,1.98e4,1.97e4,1.97e4,1.98e4]

Ftheoriem=[1.89e3,2.74e3,3.67e3,4.57e3,5.37e3,6.29e3,7.19e3,8.09e3,8.99e3,9.89e3,1.08e4,1.16e4,1.26e4,1.35e4]

safetyform=[10.48,7.21,5.40,4.33,3.67,3.15,2.74,2.45,2.20,2.00,1.83,1.70,1.57,1.47]

Frealod=[1.00e4,1.00e4,1.00e4,1.00e4,1.00e4,1.00e4,1.00e4,1.04e4,1.04e4,1.03e4,1.05e4,1.14e4,1.23e4,1.32e4]

Ftheorieod=[1.46e3,2.13e3,2.83e3,3.51e3,4.22e3,4.94e3,5.59e3,6.30e3,7.00e3,7.71e3,8.39e3,9.13e3,9.81e3,1.05e4]

safetyfactorod=[6.85,4.71,3.55,2.86,2.38,2.03,1.79,1.65,1.48,1.34,1.25,1.25,1.25,1.25]

Test conditions

Temperature: 80 ° C

Test time: 60 sec per test

Measuring frequency: 10 Hz

Filename	Torque [Nm]	Speed [rad/s]	Ratio	Line Pressure [bar]
Test1 to Test4	50 to 80	150	0.43	22
Test5 to Test8	90 to 120	250	0.43	22
Test9	130	400	0.43	28
Test12 to Test15	50 to 80	160	1.1	14
Test16 to Test19	90 to 120	250	1.1	14
Test20 to Test22	130 to 150	300	1.1	14
Test23 to Test26	50 to 80	150	2.25	7.5
Test27 to Test30	90 to 120	250	2.25	7.5
Test31 to Test33	130 to 150	300	2.25	7.5
Test34 to Test36	20 to 40	150	0.43	22
Test37 to Test49	20 to 40	150	1.1	14
Test40 to Test42	20 to 40	150	2.25	7.5