CTT – Continuous Transition Transmission – preliminary tests

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ABSTRACT

Purpose: In this paper we propose and test a new type of transmission with continuous variation, the CTT – Continuous Transition Transmission, a patented new concept of CVT - Continuous Variable Transmission, that involved friction pairs, where a smaller-diameter disk transfers motion to a larger-diameter disk through continuous variation. In the tribological tests, the objective was to find a set of pairs with the most adequate friction coefficient for the bench tests. In the bench tests the goal was to make a rough performance evaluation of the pair aluminum-PU considering the torque and power output curves of the CTT and the slip point, with the consequent loss of traction.

Methods: Tribological tests and dynamometric bench test were performed, the first using a tribometer Universal Plint & Partners TE 67 with respective fixing devices and the second a Siemens dynamometer model WBIII2GA1713, with maximum rotation and current of 3000 RPM and 3.2 A. The drive was done by a brushless electric motor brand Revolt model RV120Es of 8 kW nominal and 15 kW peak. For data collection, the bench has the MK Control CSA/ZL-20 2.00 mV/V load cell, serial number 0215 and complementary devices, being read on a notebook using LabVIEW software.

Results: With the results achieved in the tribological tests, it is possible to conclude that the contact force of the friction pair is of paramount importance in the performance of the CTT. Also, it's possible to conclude that it's also very important to perform wear tests, because some friction pairs have an accelerated characteristics lose. In the first test, the results on the dynamometric bench show that the "PU x Al" friction pair can transmit a maximum torque of 29.04 Nm with 900 RPM, resulting in 2651 watts of power. The highest power achieved was 3518 watts with a torque of 18.66 Nm at 1800 RPM.

Conclusion: Analyzing the results and considering that these are the first steps in the development of the CTT, new bench tests with different materials, dimensional variations in the friction discs, different friction forces and test drive in a small car must be carried out, in order to improve this torque and power transmission system.

Keywords: CTT, Continuous Transition Transmission, CVT, Continuous Variable Transmission, Friction Pairs, Bench tests and tribology tests.

1. Introduction

Due to the exponential increase of technological development and human population, the limitations of oil resources and the importance of environmental protection, governments around the world have enacted stringent regulations on fuel consumption and emissions. Companies, government, academic and business initiatives have been developed with the aim of reversing or at least mitigating the environmental degradation [1] [2].

Energy saving, Greenhouse Gases (GHGs) and fossil fuels depletion are critical issues for this decade. According to the World Resources Institute, emissions from the transport sector are a major contributor to climate change — about 14% of annual emissions (including non-CO2 gases) and around 25% of CO2 emissions from burning fossil fuels [3].

Growing concerns of pollution from gasoline vehicles has prompted the vigorous development of electric vehicles (EVs). Electric vehicles, as environmentally friendly vehicles, have attracted a considerable amount of attention from researchers and corporations. There are four major types of EVs, including hybrid electric vehicles (HEVs), battery electric vehicles (BEVs), plugin hybrid electric vehicles, and fuel cell electric vehicles. BEVs do not have gasoline engines and free of causing emission of greenhouse gases, since they are only driven by electricity stored in the on-board batteries [4].

Independ on the type of EVs, the driveline efficiency can significantly affect car fuel economy. Studies on the efficiency of CVT and gearbox have been conducted through bench tests in all the world (CITAR). According to Lei et al., the transmissions systems have an important contribution at the efficiency of the power train [5].

Transmissions has been developed in different configurations over the years in order to improve the drive agreement and reduce the energy consumption. Different types of transmission like manual, automatic, automated and continuously variable has been tested, among then, transmissions with continuous variation are the best beat [6] [7]. The main types of these transmissions are: Variable-Diameter Pulley (VDP), Toroidal CVT (T-CVT) and CVT Friction Conic (CVT Cone).

Physical limitations of strength and friction have in the past restricted the CVT transmission torque. However, the necessity for improved vehicle efficiency combined with advancements in lubricants and materials have sparked new interests in CVTs [8].

Gong indicated that a Continuous Variable Transmission (CVT) allowed a drivetrain controller the freedom to develop a required output power at a range of engine torque and speed conditions. This flexibility can be used to maximize efficiency [9] [10]. Recent transmission systems introduce a new degree of freedom in the system, which can be used to develop more efficient Energy Management Strategy (EMS) [11].

A new type of transmission with continuous variation, the CTT – Continuous Transition Transmission, a patented new concept of CVT - Continuous Variable Transmission, is presented here. The principle of

the CTT transmission is based on contact discs, where a Drivedisk (Traction Disc) transfers the movement of the electric motor to a disc with a larger diameter, the Flywheel (Transmission DIsc). In the initial avaliation the CTT was assembled in an electric bicycle which has been driven for over 900 km under typical usage conditions performing with great battery range and no visible wear. In this proof-of-concept, it was possible to evaluate the technical feasibility of CTT. The friction pair used was the “Flywheel aluminum x Drivedisk PU”, reference in all tests realized.
The purpose of this work is to measure, through tribological tests, the performance of different contact pairs (flywheel x drivedisk) and to realize a test bench with the reference pair on a dynamometer bench.

2. CTT – Continuous Transition Transmission

The friction in the contact point between the drive disks and the flywheel is critical for the proper transmission functioning. The configuration of the system undergoing tests has a dry flywheel drivedisk contact point, using a PU coat on the drivedisk and an aluminum flywheel. With this configuration, we were able the get a satisfactory torque transmission, while reducing the wear of the drive disk
As the disc shafts are positioned at 90° to each other, this allows for the transition of the Drive Disc contact point along the Drive Disc radius, thus continuously changing the relationship between the Disc's fixed diameter (input) and the variable point dynamometer where the Drive Disc touches the radius of the Drive Disc (output). Figure 1 shows the schematic Flywheel and the Drivedisk in a single configuration with only one drive disk for simplicity.

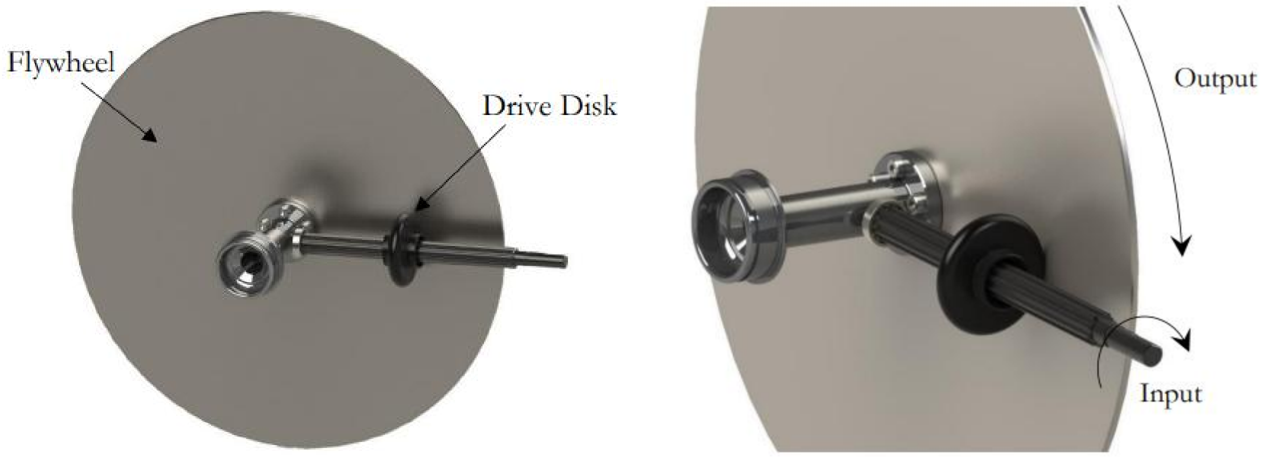

Figure 1: Schematic Flywheel and Drivedisk in a single configuration

The position of the drive disk can be controlled by tilting its axis. If the drive disk axis is parallel to the flywheel radius, it will keep its position, but if the drive disk leans toward the flywheel center, it will move forward, reducing its distance to the flywheel center, and thus, the transmission ratio. This mechanism can be better seen in the Figures 2 and 3. The rotational motion of the Input Output Flywheel Drive Disk (green arrow) implies a translation motion (red arrow). In the single configuration of the system, another drive disk is built in symmetrically to the first one, in order to increase the flywheel´s stability.

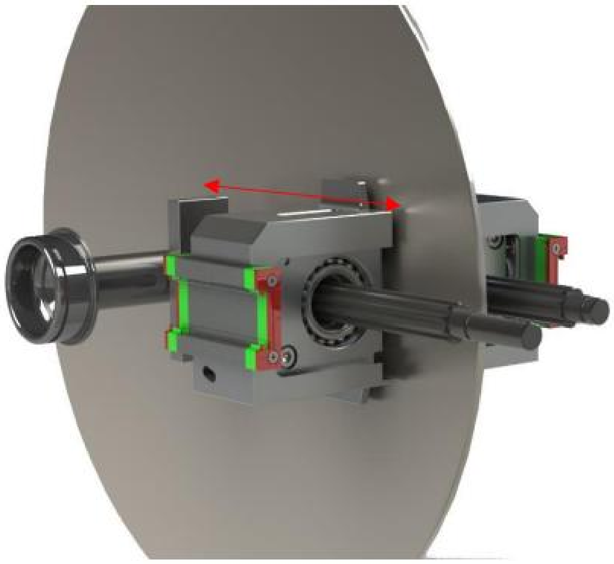

Figure 2: Flywheel with drive disk housing in a single configuration

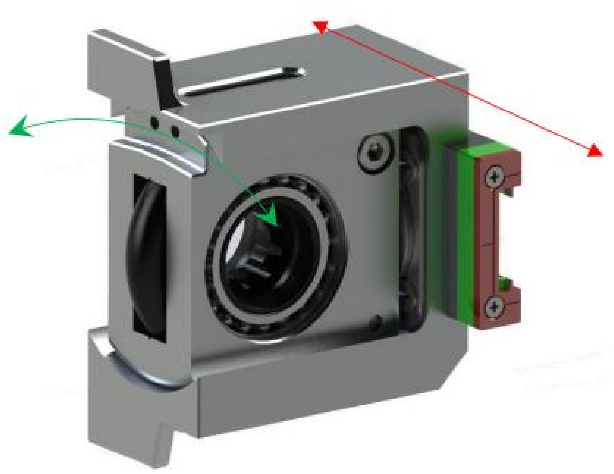

Figure 3: Drivedisk inside housing

The CTT is currently patented in nearly 20 countries, including in the US under the registry number US 906863382.

3. Methodological approach

The purpose of this work is to measure, through tribological tests, the performance of different contact pairs (flywheel x drivedisk) and select some pairs for testing on a dynamometer bench, aiming to evaluate the technical feasibility of CTT and the possibility of future vehicular application.

3.1 Tribology tests

In the tribological tests, the objective was to select the pairs with the most adequate friction coefficient for the bench tests. Tribological tests were performed using a tribometer Universal Plint & Partners TE 67 with respective fixing devices.

Tribological tests were performed with the friction pairs shown in the Table 1. The tests of the friction pairs were made considering the speed and the respective forces applied. Its methodological approach is represented in the Figure 4. The tests aim to find the average friction coefficient and the wear rate of the evaluated friction pairs.

	DISCO	ROLETE	FORÇA (N)	VELOCIDADE (RPM)
01	Alumínio	PU	100	500
02			200	
03		Alumínio	100	
04			200	
05		Aço	100	
06			200	
07	Material Compósito	PU	100	500
08			200	
09		Alumínio	100	
10			200	
11		Aço	100	
12			200	
13	Aço	PU	100	500
14			200	
15		Alumínio	100	
16			200	
17		Aço	100	
18			200	

Table 1: Tested friction pairs, speed used and the respective forces applied

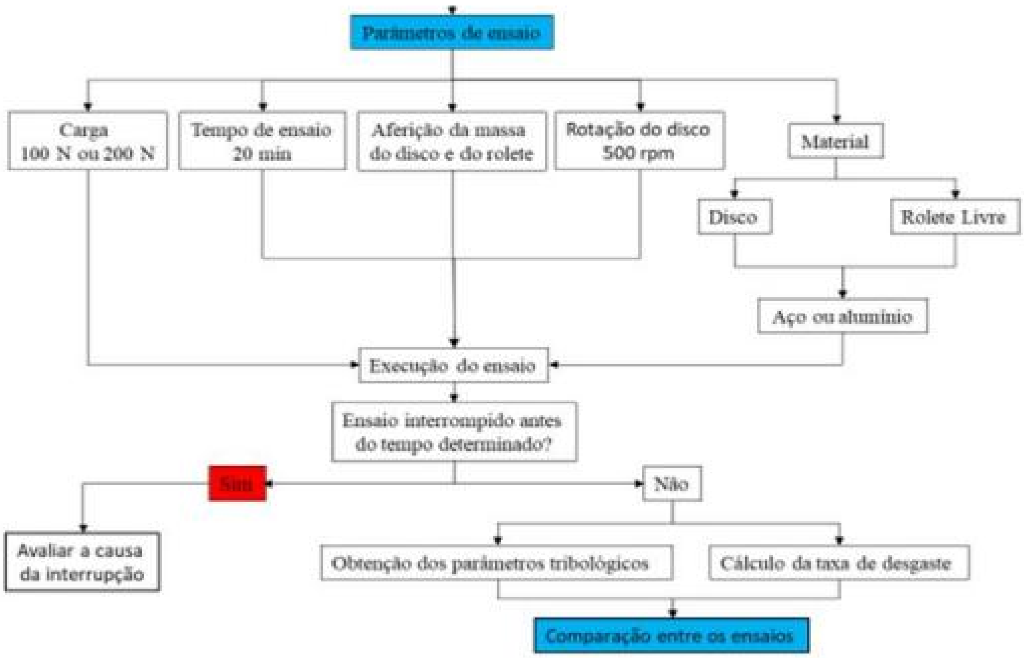

Figure 4: Methodological Approach

3.2 Bench Tests

The goal of this test is to make a rough performance evaluation of the friction pairs on a test bench, considering the torque and power output curves of the CTT and the slip point, that is, to determine the maximum torque and power that the CTT can transmit without sliding between its friction pairs, roller and disc, with the consequent loss of traction. In this test, the friction pair used was the “Flywheel aluminum x Drivedisk PU”, our reference friction pair.

To carry out the initial dynamometer tests, the CTT was mounted on a test bench consisting of a Siemens dynamometric brake model WBIII2GA1713 with maximum rotation and current of 3000 RPM and 3.2 A, respectively, and driven by a brushless electric motor brand Revolt model RV120Es 8 kW nominal and 15 kW peak. For data collection, the bench has a MK Control CSA/ZL-20 2.00 mV/V load cell, serial number 0215 and complementary devices, being read on a notebook using the LabView software.

When coupled to the electromagnetic dynamometer, the instrumentation and software used allow the application of torque to the motor and the measurement of the desired quantities, such as: torque, rotation, power, voltage and input current. In addition to showing the slip point, with the consequent loss of traction.

Due to the dynamometer characteristics the test was restricted to the maximum rotation of 3000 RPM and 50% of the maximum torque. The methodology used in the bench test was:

- Elevation of motor speed up to 3000 RPM;
- Activation of the electromagnetic brake seeking the rotations of (RPM): 3000, 2700, 2400, 2100, 1800, 1500, 1200, 900, 600 e 300;
- Accelerator scoring 5 laps out of 10;
- Torque, rotation speed, input voltage and current read in the LabView;
- Power calculation.

4. Results and discussion

4.1 – Tribological tests

Figure 5 shows the average of the friction coefficient from all tribological tests in a single graph. The results obtained in all tests referring to the friction coefficient, from which it is possible to verify:

- The normal force exerts great influence on the tribological parameters. The higher friction force (200 N) induced higher friction coefficients, reaching 3.2 times in the aluminum-aluminum friction pair and 6.7 times in the composite-steel pair, compared with 100 N friction force;
- The highest friction coefficient obtained was with the aluminum disc/aluminum roller pair, with 200 N of normal load ($\mu = 0.071$). The friction pair of aluminum disc/steel roller with 200 N of normal load, presented a close average friction coefficient ($\mu = 0.069$); and
- In turn, the composite disc-steel roller pair had the lowest friction coefficient (0.004). This value has the lowest order of magnitude of all other measurements taken. The test of the composite disc-aluminum roller pair presented problems and was therefore discarded.

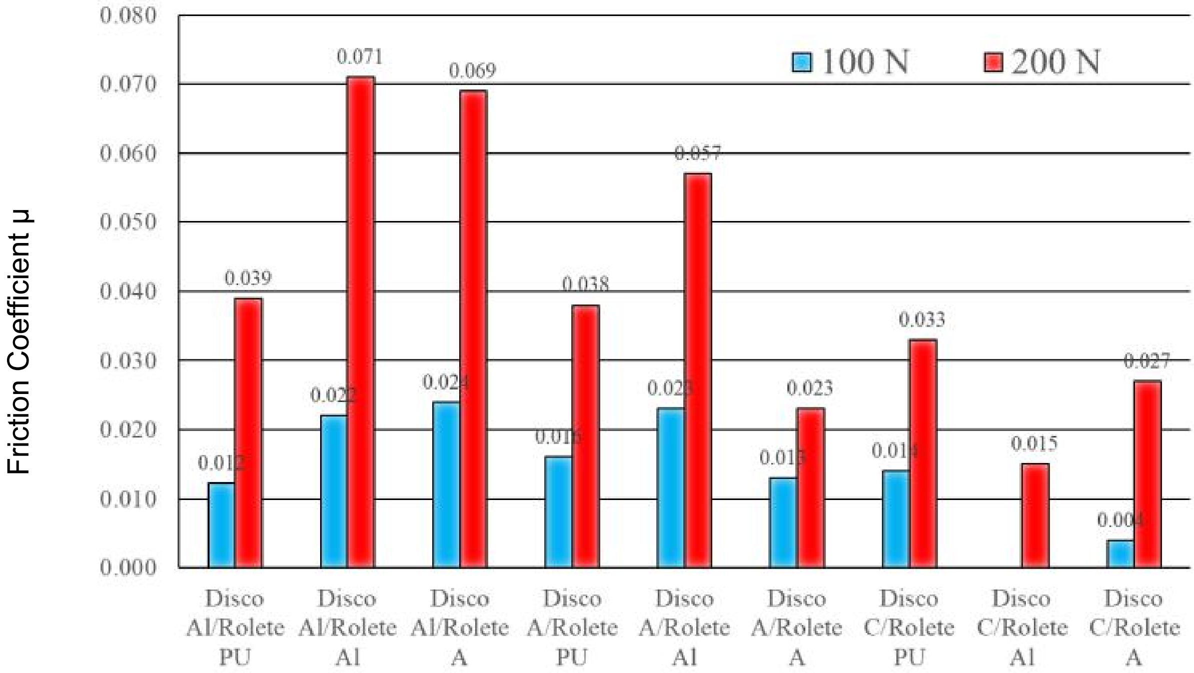

Figure 5: Effect of normal force on the friction coefficient

Considering that the effect of normal force on wear is a complex task, it's necessary to have in mind that what is important is the wear system. Figure 6 shows the average of the wear rate from all tribological tests in a single graph, from which it is possible to verify:

- Once again, in general, the greater normal force induces greater wear, except for the pairs of the steel-aluminum and steel-steel, which presented mass gain in the system due to the greater mass gain of the flywheel greater than the drivedisk mass loss.
- The wear rate associated with the aluminum-aluminum pair with 200 N deserves to be highlighted, because, in addition to having the highest friction coefficient among the selected pairs, it has an acceptable wear rate, with 54.75 [$g.N^{-1}$ $.m^{-1}$]$.10^{-8}$). The aluminum-steel pair has similar values.
- Finally, the disc of the composite disc-steel roller pair tested at 200 N showed a much higher wear rate (order of magnitude) than the others. This fact may result from imperfections (cracks) in the coating.

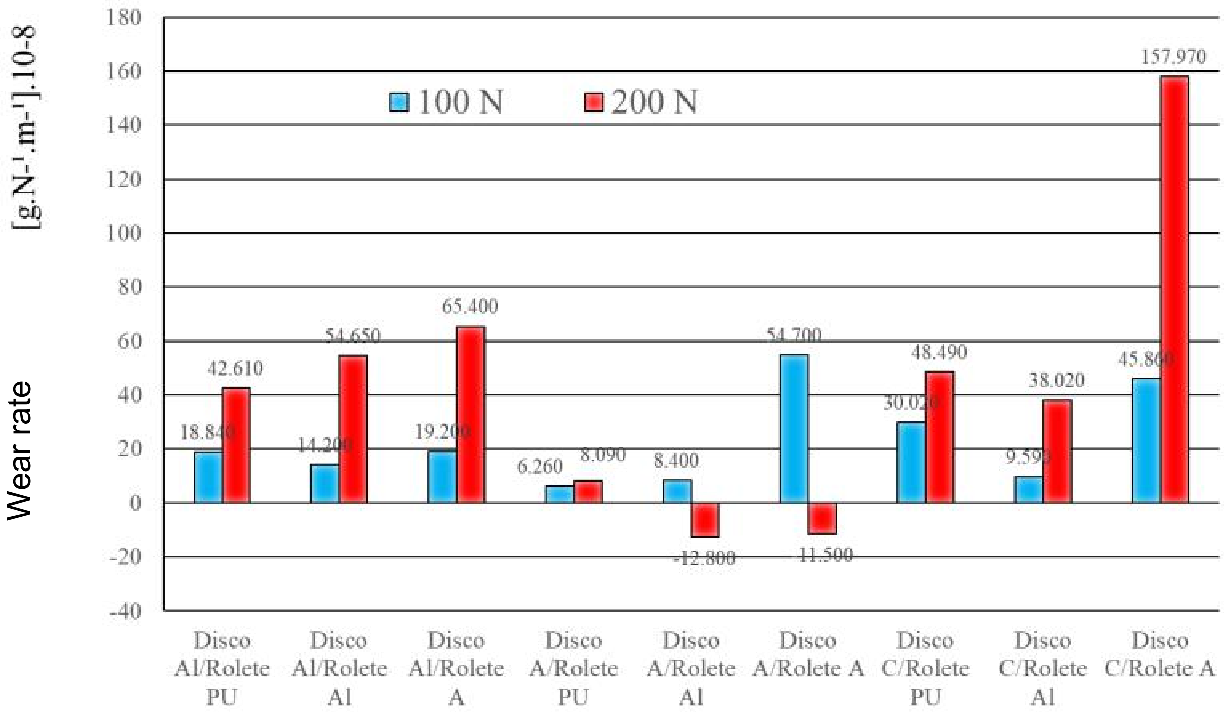

Figure 6 - Effect of normal force on the wear rate system.

4.2 – Bench tests

Table 2 shows the values found in the dynamometric bench test, with the “Flywheel aluminum x Drivedisk PU” friction pair. The data showed are the average of three measurements.

The values in the table were measured using the following means of measurement:

- Electric motor rotation (RPM): Dynamometer measurement - LabView
- Input torque (Nm): Dynamometer measurement - LabView
- Output torque (Nm): Input torque x Flywhell-Drivedisk relationship (5,635)
- Power (Watts): Calculated (Torque x angular speed)
- Input voltage (V): Dynamometer measurement - LabView
- Input Current (A): Dynamometer measurement - LabView
- Dynamometer acceleration: 5,2

Nos testes efetuados, below 300 RPM, the electric motor stalled, not generating data. Input voltage and input current values were not measured for 600 and 300 RPM rotations.

Rotation RPM	Input Torque Nm	Output Torque Nm	Power W	Input Voltage V	Input Current A
3016	1,05	5,92	332	64,6	8,69
2682	5,83	32,85	1637	63,3	27,8
2467	8,93	50,32	2307	62,0	44,8
2033	15,81	89,09	3366	60,9	64,9
1800	18,66	105,15	3518	60,9	69,2
1501	21,83	123,01	3431	59,3	70,6
1200	25,40	143,13	3192	58,3	71,8
960	27,32	153,95	2746	56,1	71,8
600	22,10	124,53	1389	------	------
300	17,46	81,48	548	------	------

Table 2 – Values measured on the dynamometric bench with aluminum disc and PU roller.

5. Conclusions

With the results achieved in the tribological tests, it is possible to conclude that the contact force of the friction pair is of paramount importance in the performance of the CTT, therefore, it will be necessary to have a good hydraulic or electronic system to control this force and probably with traction control, to obtain the best performance from the CTT.

In the first test, the results on the dynamometric bench show that the “PU x Al” friction pair can transmit a maximum torque of 29.04 Nm with 900 RPM, resulting in 2651 watts of power. The highest power achieved was 3518 watts with a torque of 18.66 Nm at 1800 RPM.

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