

# Some considerations about the effect of grooves on the viscous coupling performances

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**Abstract.** A viscous coupling transmits torque by viscous shearing of the oil film between one or multiple pairs of discs that are in relative motion one to the other. A viscous coupling uses a viscous fluid as a working medium and performs best in full film lubrication condition. A continuous film of oil must be present at all times between the two surfaces that are in relative motion. Only in this stage, when operating in full film lubrication condition, this coupling can achieve the maximum transmission of torque. This kind of study is of a great importance since this coupling is widely used all around the world in all sorts of applications. In this paper, the effect of grooves on the viscous coupling performances was carried out deeply using a Computational Fluid Dynamics Software. The flow of the fluid film and shear torque between the friction pair are complex and keep changing with the operating conditions, the geometry, the number of grooves, the properties of the working oil and the thickness of the oil film.

## 1. Introduction

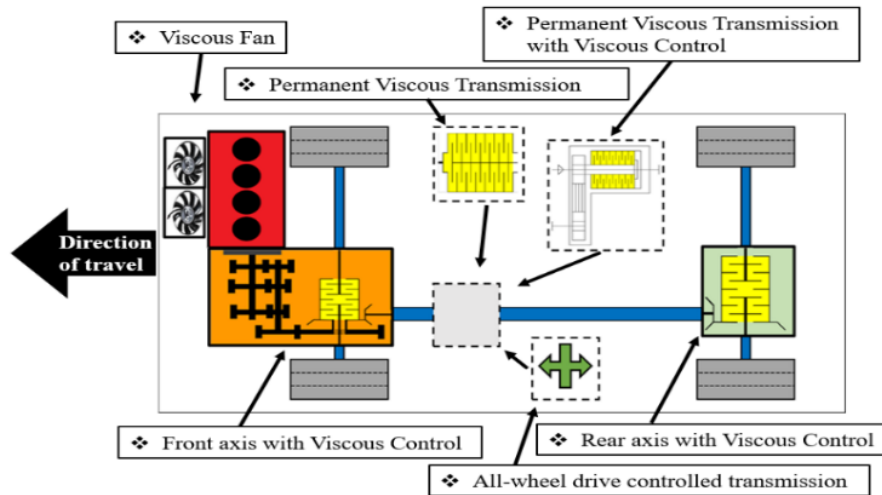
As technology progresses, engineers are continuously seeking for new improvements in the auto industry sector in every way possible in order to increase consumer experience and comfort. Viscous couplings present a high interest when developing comfortable and performant drive trains due to their advantages. Viscous couplings are widely studied in all sorts of applications such as fan transmission in vehicles (viscous fan clutches) [1], pumps, winches (hydro-viscous winch) [2], mechanism of belt conveyors [3], wind turbines [4], tunnel boring machines (TBM with viscous clutch) [5].

In this paper the effects of grooves on the viscous coupling performances device are studied thoroughly in different settings such as different speeds, different number of grooves, the properties of the working oil and the thickness of the oil film. Below in figure 1 we can see different variants for placing a viscous coupling in a car [1].

### Nomenclature

$M_t$  (Nm) - transmission torque  
 $\eta$  (Pas) - dynamic viscosity (oil)  
 $\omega_1$  (rads<sup>-1</sup>) - angular speed of the rotating grooved disc  
 $\omega_2$  (rad<sup>-1</sup>) - angular speed of the stationary smooth disc  
 $r_e$  (mm) - external radius of the disc  
 $r_i$  (mm) - internal radius of the disc  
 $h$  (mm) - thickness of the oil film  
 $z$  (mm) - number of oil films



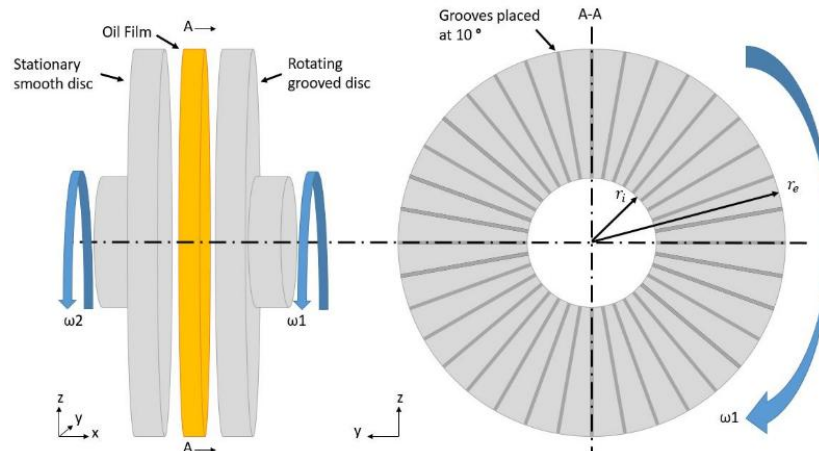


**Figure 1.** Different variants for placing a viscous coupling in a car

## 2. Mathematical modelling of a viscous coupling

### 2.1. Basic operating principle

The functioning of a viscous coupling is based on the Newton's law of viscosity, and works by transferring the power through the viscous shear force of the oil film. In order to transmit torque, there has to be both a thin and continuous film of oil and also an angular speed difference between the two surfaces that are in relative motion one to the other. A schematic drawing is presented in figure 2.



**Figure 2.** Schematic drawing of a viscous coupling

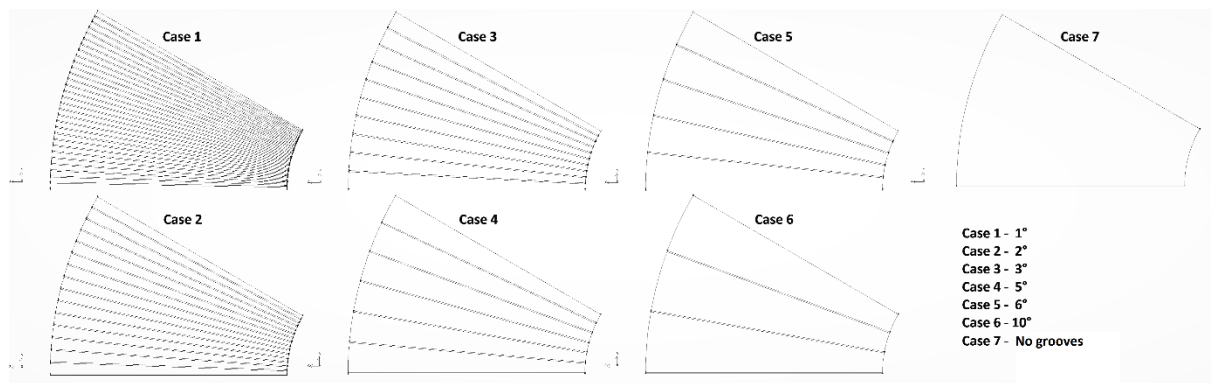
The torque calculation model of a viscous coupling is shown below and can be obtained by [6]:

$$M_t = z\pi\eta(\omega_1 - \omega_2) \frac{r_o^4 - r_i^4}{2h} \quad (1)$$

## 3. CFD model development

### 3.1. Designing of the 3D model

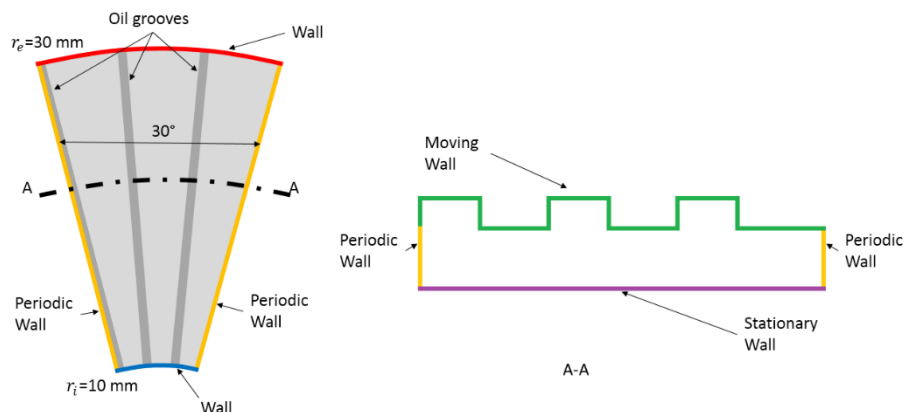
The geometrical model of the viscous coupling was built in a pre-processing software. In order to better study the phenomenon, the geometrical model was simplified and the 1/12 representing 30° of the full model was analysed using Computational Fluid Dynamics Software. Also, there were considered 5 different groove depths, 4 different oil thicknesses and there were chosen 7 different geometrical models as shown in figure 3.



**Figure 3.** The geometrical models that were chosen for the CFD analysis

### 3.2. Boundary conditions

The boundary conditions were assigned in the pre-processing software. As shown in figure 4, stationary wall boundary condition was assigned for the external radius surface, internal radius surface and for the stationary smooth disc surface. Since the model is simplified to a 30° of the full model, periodic rotational boundary condition was assigned for both of the side surfaces and for the remaining rotating grooved disc surface, rotating wall boundary condition was selected. The internal volume of the model was considered to be of a fluid continuum type. After the assigning of the boundary conditions, the meshing of the volume was performed. Quad elements were used for the meshing of all the faces of the model and Hex elements were used for the meshing of the models volume and in both cases the type of the meshing was Map.



**Figure 4.** Assignment of the boundary conditions for the simplified model

### 3.3. Pre-processing

The numerical simulation was carried out in a CFD software, with 3ddp precision (three-dimensional double precision). After scaling the model to its proper original size, the boundary conditions were reviewed and conditions were set. The entire study was carried out using speeds ranging from 10 up to 300 ( $\text{rads}^{-1}$ ). An oil was selected from the material database but with the viscosity changed from constant to power-law with Three Coefficient Method using 3 reference viscosities 0.02, 0.58 and 1.06 (Pas). The reference temperature was set in all cases to be 300 (K) and. Also, in this stage the Energy Equation was selected. Furthermore, Laminar Model was chosen for the study of the simplified viscous model.

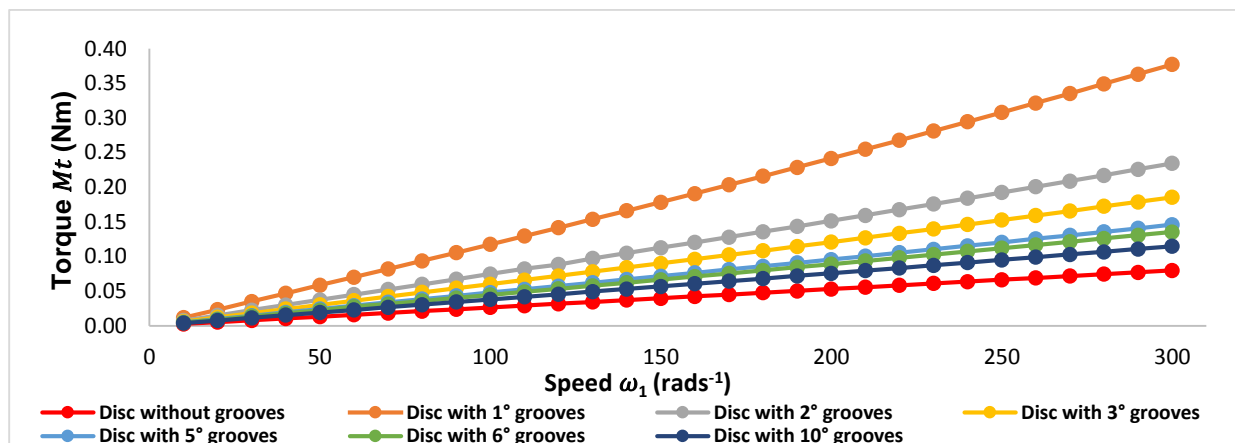
After setting all the conditions, the initialization and iteration of the model followed.

#### 4. CFD simulation results

##### 4.1. Analysis of transmission torque considering the different groove placements

For this analysis, there were used 6 discs with grooves placed at  $1^\circ$ ,  $2^\circ$ ,  $3^\circ$ ,  $5^\circ$ ,  $6^\circ$  and  $10^\circ$ , the textured area density is between 10% and 70%. The viscosity of the oil was chosen 0.02 (Pas) and the thickness of the oil film is 0.1 mm. The depth of the groove is 0.05 mm and the width of the grooves is 0.10 mm.

Upon analysing of the graph from figure 5 it can be seen that the torque increases with the increase of the speed. Furthermore, from the same graph it can be clearly seen that the torque increases if the number of radial grooves increases. Also, it can be seen that the torque transmitted is not linear, for example a much steeper slope is the one representing the disc with  $1^\circ$  grooves on it.

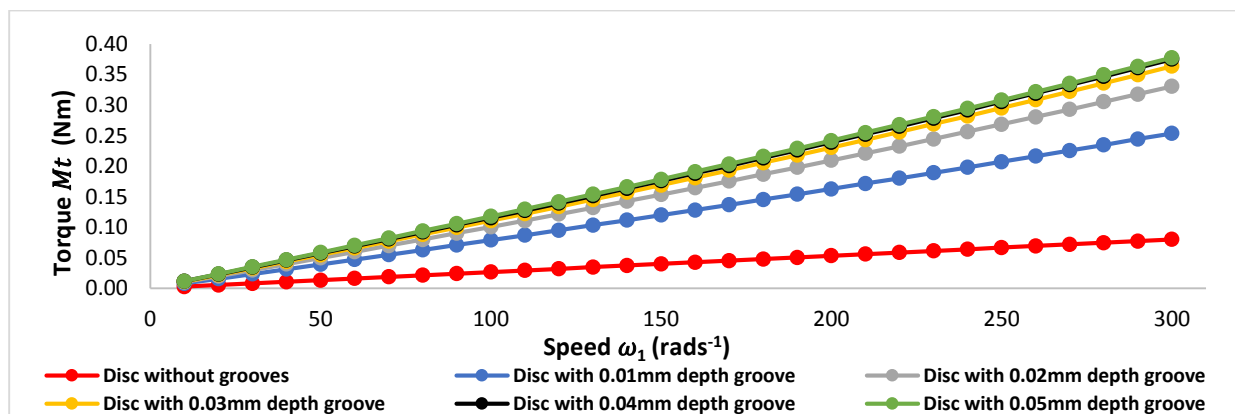


**Figure 5.** Torque generated at different angular speeds by discs with different groove placements

##### 4.2. Analysis of transmission torque considering the different groove depths

For this analysis, there were used 5 discs with grooves placed at  $10^\circ$  and 1 disc without any grooves. The disc with grooves has depths ranging from 0.01 mm up until 0.05 mm. The viscosity of the oil is 0.02 (Pas), the thickness of the oil film is 0.1 mm and the width of the grooves is 0.10 mm.

Upon analysing of the graph from figure 6 it can be seen that the torque increases with the increase of speed and with the increase of the grooves' depths. Furthermore, from the same graph it can be clearly seen that the torque transmitted increases until it reaches about the same value at 0.04 mm ~ 0.05 mm depth of the groove.

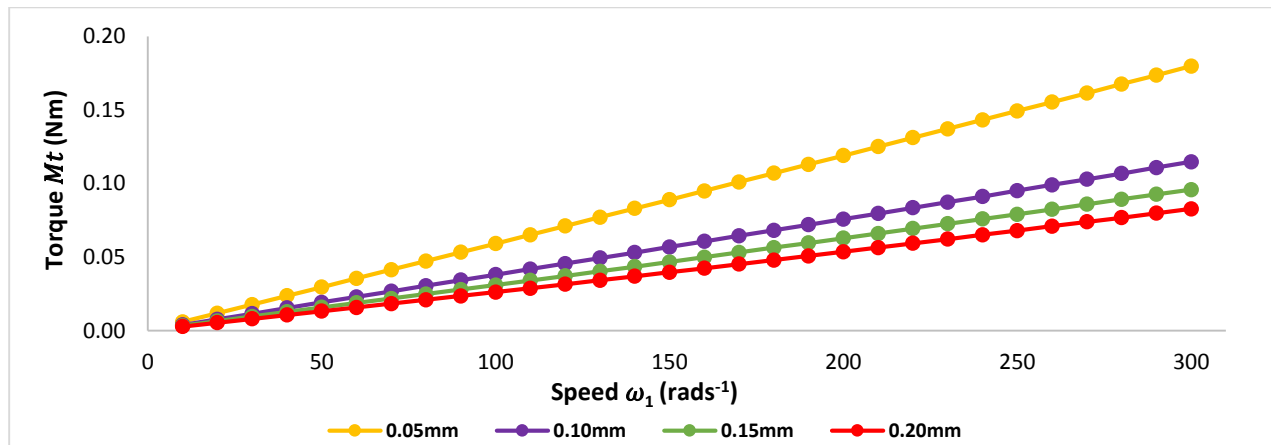


**Figure 6.** Torque generated at different angular speeds by a disc with 5 different groove depths

#### 4.3. Analysis of transmission torque considering the different oil thicknesses

For this analysis, there were used 4 different oil thicknesses ranging from 0.05 mm and up to 0.20 mm. The disc used has grooves placed at  $10^\circ$ , the channel's depth is 0.05 mm and the width of the grooves is 0.10 mm. The viscosity of the oil was chosen 0.02 (Pas).

Upon analysing of the graph from figure 7 it can be seen that the torque increases with the increase of speed and with the decrease of the oil thickness found between the discs. Also, it can be seen that the torque transmitted is not linear, for example a much steeper slope is the one representing the oil thickness of 0.05 mm.

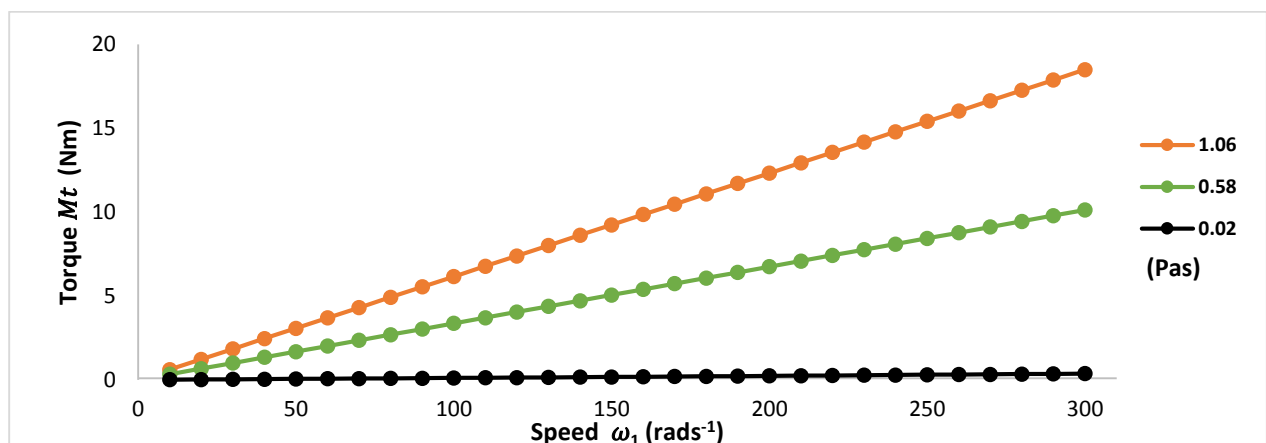


**Figure 7.** Torque generated at different angular speeds by a disc with 4 different oil thicknesses

#### 4.4. Analysis of transmission torque considering the different oil viscosities

For this analysis, there were used 3 different oil viscosities: 0.02, 0.58, 1.06 (Pas). The disc used has grooves placed at  $10^\circ$ , the channel has depth of 0.05 mm and the width of the grooves is 0.10 mm.

Upon analysing of the graph from figure 8 it can be seen that the torque increases with the increase of speed and with the increase of the oil's viscosity found between the discs. Also from the graph it can be observed that the oil that has a viscosity of 0.02 (Pas) can barely transmit a torque of no more than 1 (Nm) at an angular speed of 300 (rads $^{-1}$ ).



**Figure 8.** Torque generated at different angular speeds by a disc with 3 different oil viscosities

Due to the short operating time, the regime can be considered stationary with constant viscosity.

## 5. Conclusions and future work

### 5.1. Conclusions

Based on the present investigation that was carried out, the results are summarized as follows:

1. In all cases regardless of the number of grooves that are present on the disc or groove depths or viscosity values or oil thicknesses, the torque increases with the angular speed.
2. The torque increases if the number of radial grooves increases.
3. The torque increases with the grooves' depths until it reaches about the same values at about 0.04 mm ~ 0.05 mm depth.
4. The torque decreases with the increase of the thickness of oil film.
5. The torque values are directly proportional with the oil's viscosity.

### 5.2. Future work

Future work will focus on the validation of the mathematical model with an experimental test rig. Also future work will focus on the geometry of the grooves. In this paper only straight radial grooves are studied but for future work a much complex geometry and shapes will be taken into consideration. Different widths of the grooves will be also studied. In this paper only one value of the groove width 0.05 mm, is studied.

## References

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