

KÖRMÖS TENGELYKAPCSOLÓ KAPCSOLÁS KINEMATIKAI MODELLJE

KINEMATICAL MODEL OF THE DOG CLUTCH SHIFTING

Ayham Aljawabrah, PhD Student, aaljawabrah@edu.bme.hu
Dr. László Lovas, associate professor, lovas.laszlo@kjk.bme.hu
BME Department of Railway Vehicles and Vehicle System Analysis

ABSTRACT

This paper studies the shiftability of the face dog clutch. A kinematic model describing the engagement of the dog clutch is developed and the shiftability condition is determined. Parameters affecting the shiftability are shown. Shiftability regions are determined by an analytical method.

1. INTRODUCTION

The use of internal combustion engines in motor vehicles arises the need to transmit the engine input torque at different output gear ratios to meet all operating conditions. Thus, a mechanism was needed to direct and switch the engine input among the different gear ratios.

Firstly, the synchronizer was developed to accomplish the task, as studied in the literature [1]. The recent development in vehicles focuses on lightweight and simple mechanical structures. Compared to the synchromesh, the dog teeth clutch provides quicker shifting time, simpler structure, larger power transmitting capacity, and has lower cost. As it is only a clutch and not a synchronizer, the problems of synchronization and shiftability have to be resolved.

Many researchers studied the gear shift process. Bóka studied the dog clutch application in automatized mechanical transmission (AMT) for heavy-duty commercial vehicles [2-4]. He used the notion of engagement probability to find a certain successful region depending on the initial mismatch speed [4], but his results were applied to the zone of low mismatch speed. The zone of high mismatch speeds (ex: motorbikes, electric motors) remained unexplained. Later on, Farkas [5] investigated the engagement process from a kinematical point of view. He developed a geometric condition for the successful engagement under constant axial speed condition and developed a two-dimensional

shiftability map. His results showed a periodicity in the successful shifting region. Besides the theoretical study, experimental test rigs, similar to [6], should be developed for theory testing.

This paper intends to follow the path drawn by Bóka and Farkas. The kinematics of a dog teeth clutch shifting will be discussed. Based on that, a generalized equation on engagement probability at any mismatch speed will be built and verified upon literature data.

2. DOG CLUTCH GEOMETRIC MODEL

2.1. Structure of a dog clutch

A dog clutch is a coupling used to transmit power. It consists of two parts having complementary geometry. These complementary shapes are referred to as dog teeth. Teeth can be present either on the circumference of a cylinder (radial clutch or spline clutch) or on the circular surface of the cylinder (axial clutch or face clutch). Radial dog teeth clutches are traditionally used for power transmission in automotive gearboxes (cars, trucks, buses) as a part of the synchronizer. Axial dog teeth clutches are traditionally used for power transmission in motorbike gearboxes, where the torque is much less than in a truck case. In this study, axial dog teeth clutches are considered. However, the described method can be applied independently of the place of the geometry.

Let us consider a dog teeth clutch composed of an axially moving part called sliding sleeve (s) and an axially fixed, but rotating part called the shifted gear. (g) The coupling is realized by the axial motion of the sliding sleeve (Figure 1).

The main geometry parameters are presented in Table 1. The dog geometry is shown in Figure 2 At the beginning of the shifting, the sliding sleeve and the shifted gear have an axial

gap x_0 and initial relative angular position ξ_0 between the marked teeth. Figure 3a shows further parameters. Here the sliding dog can slide axially with a speed v_0 , while it has relative angular rotation regarding the target gear. The relative angular rotation is called the initial mismatch speed $\Delta\omega_0$. The engagement of the complementary geometries is eased with an angular backlash Φ_b .

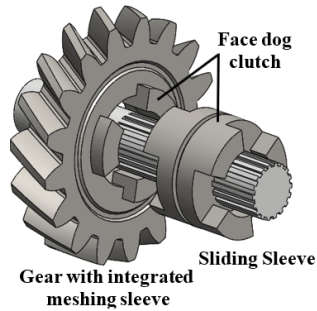


Figure 1. Face dog clutch

Table 1: Dog clutch shiftability parameters

Parameter	Unit	Parameter	Unit
Initial relative position ξ_0	[°]	Angular backlash Φ_b	[°]
Mismatch speed $\Delta\omega_0$	[rad/s] ([RPM])	Overlap distance x_{fed}	[mm]
Axial Speed v_0	[mm/s]	Axial gap x_0	[mm]
		Teeth Number Z	[-]

The axial dog clutch has an angular pitch ϕ given by Eq.(1) and an angular backlash Φ_b given according to Eq.(2), where ϕ_t is the tooth thickness angle.

$$\phi = \frac{2\pi}{Z} \quad (1)$$

$$\Phi_b = \phi - 2\phi_t \quad (2)$$

2.2. Modeling of the dog clutch

The shifting process is analyzed from a kinematical point of view. The following assumptions are used:

- The axial speed for the sliding sleeve is constant
- The angular mismatch speed is constant.
- The effect of the teeth' impact and friction is neglected.

For easier understanding, the dog teeth geometries are rolled out and visualized as having linear motion.

Between the sliding sleeve and the meshing gear, it exists a mismatch speed $\Delta\omega_0$ and an axial gap x_0 Figure 3a). The engagement

of the dog clutch is realized by the axial motion of the sliding sleeve. At the beginning of the shifting, the sliding dog moves axially with speed, or mean linear velocity, of v_0 until the axial gap is removed (Figure 3b). The time required is given by Eq.(3):

$$t' = \frac{x_0}{v_0} \quad (3)$$

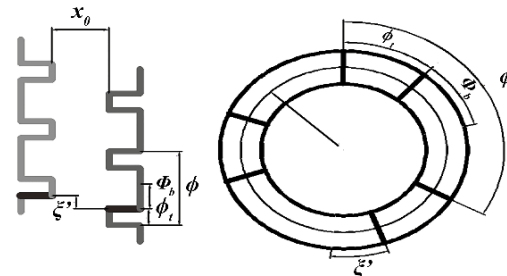


Figure 2. Dog clutch geometry

During this time, the dog clutch parts rotate relative to each other, and the relative angular position changes from ξ_0 to ξ' according to Eq.(4), and as shown in Figure 3b.

$$\xi' = \xi_0 + \Delta\omega_0 t' = \xi_0 + \Delta\omega_0 \frac{x_0}{v_0} \quad (4)$$

We suppose that a successful engagement happens when an overlap x_{fed} is reached in the axial direction (Figure 3c). The time required for the overlap is given by Eq.(5):

$$t'' = \frac{x_{fed}}{v_0} \quad (5)$$

While reaching the overlap, a relative rotation between the dog clutch and the target gear occurs as shown in Figure 3c, and is given by Eq.(6):

$$\Delta\varphi = \Delta\omega_0 t'' \quad (6)$$

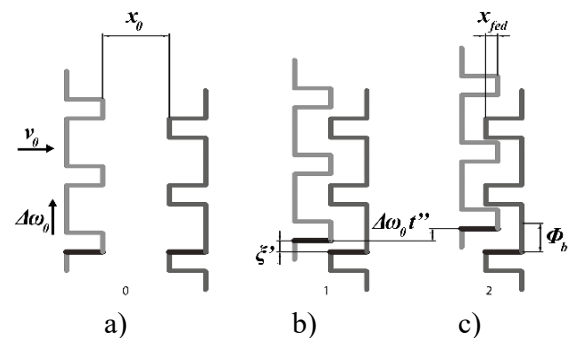


Figure 3. Dog clutch engagement stages

The dog clutch engagement can occur under different conditions. These conditions are characterized by initial relative position ξ_0 and mismatch speed $\Delta\omega_0$ values.

Firstly, the initial relative position and the mismatch speed are both equal to zero. The steps of the engagement are shown in Figure 4. The index 0 represents the initial state, 1 the end of the axial gap removal, 2 the reaching of the overlap, and 3 complete engagement when the

sliding sleeve covers the full tooth height in the axial direction, not shown in the figure.

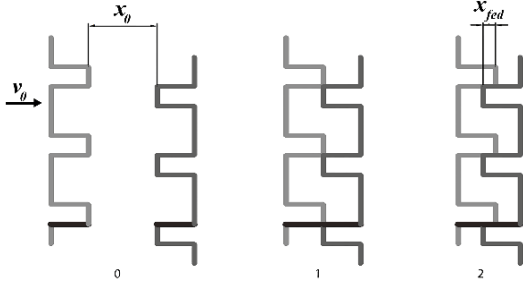


Figure 4. Dog clutch engagement with $\xi=0$, and $\Delta\omega_0=0$

For a successful shifting, the traveled distance should be larger than the sum of the axial gap and the overlap distance, see Eq.(7):

$$x \geq x_0 + x_{fed} \quad (7)$$

This condition is valid till ξ_0 is less than the angular backlash Φ_b . When the initial relative position is not zero (Figure 5), an additional condition is required, as illustrated in Eq.(8):

$$\xi_0 \leq \Phi_b \quad (8)$$

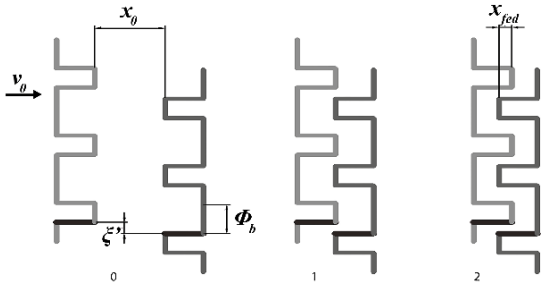


Figure 5. Dog clutch engagement with $\xi > 0$, and $\Delta\omega_0=0$

In the second case, the initial relative position ξ_0 is zero, but the mismatch speed is not zero. For a successful engagement, angular backlash must be present. By the end of the engagement, the relative position should be less than the angular backlash (Figure 3).

$$\xi' + \Delta\omega_0 t'' \leq \Phi_b \quad (9)$$

Using Eq.(4), this condition is formed in Eq.(10):

$$\Delta\omega_0 t' + \Delta\omega_0 t'' \leq \Phi_b \quad (10)$$

In the third case, the initial position is zero, but the mismatch speed is much larger than zero. Here a tooth on the sliding sleeve can catch not only the next but the second tooth gap on the shifted gear, as shown in Figure 6. To describe this, the shifting condition described in Eq.(9) is not sufficient, and a further condition is required, as shown in Eq.(11):

$$\xi' \geq \phi \quad (11)$$

Eq.(9) can be rearranged to Eq.(12):

$$\Delta\omega_0 t' \leq \phi + \Phi_b - \Delta\omega_0 t'' \quad (12)$$

Substituting Eq.(4) into Eq.(11) and combining it with Eq.(12) gives the condition in Eq.(13):

$$\phi \leq \Delta\omega_0 t' \leq \phi + \Phi_b - \Delta\omega_0 t'' \quad (13)$$

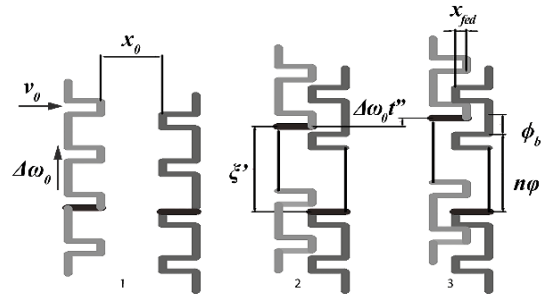


Figure 6. Dog clutch engagement with $\xi=0$ and $\Delta\omega_0 >> 0$

Generally, when the mismatch speed is very high, a tooth on the sliding sleeve can pass n teeth on the target gear, as Figure 7 shows. A generalized condition from Eq.(13) is introduced in Eq.(14). The value of the integer n is calculated according to Eq.(15), where the bracket $[]$ refers to the integer part.

$$n\phi \leq \Delta\omega_0 t' \leq n\phi + \Phi_b - \Delta\omega_0 t'' \quad (14)$$

$$n = \left[\frac{\xi'}{\phi} \right] \quad (15)$$

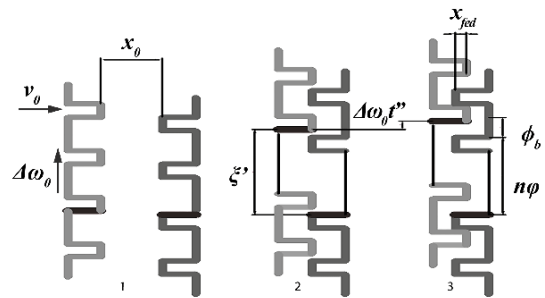


Figure 7. Dog clutch engagement with $\xi=0$ and $\Delta\omega_0 >> 0$ with n teeth passing

Finally, when the initial relative position is larger than zero, the generalized shiftability condition can be introduced according to Eq.(16):

$$n\phi \leq \xi_0 + \Delta\omega_0 t' \leq n\phi + \Phi_b - \Delta\omega_0 t'' \quad (16)$$

Substituting the values for ϕ , t' , t'' , and n from Eqs. (1), (3), (5), and (15), respectively, Eq.(16) can be implemented with the geometric and kinematic parameters, forming Eq.(17). Eq.(17) can also be written with *mod* function as shown in Eq.(18):

$$0 \leq \xi_0 + \Delta\omega_0 \frac{x_0}{v_0} - \left[\frac{\xi_0 + \Delta\omega_0 \frac{x_0}{v_0}}{\frac{2\pi}{z}} \right] \frac{2\pi}{z} \leq \Phi_b - \Delta\omega_0 \frac{x_{fed}}{v_0} \quad (17)$$

$$0 \leq \text{mod} \left(\xi_0 + \Delta\omega_0 \frac{x_0}{v_0}, \frac{2\pi}{z} \right) \leq \Phi_b - \Delta\omega_0 \frac{x_{fed}}{v_0} \quad (18)$$

The condition in Eq.(18) is developed for the case when the initial relative position ξ_0 and the initial mismatch speed $\Delta\omega_0$ are both positive. To account for the case when the initial relative position is negative, the middle part of Eq.(18) has to be in the first positive cycle $(0, \phi)$. If the middle part is in the negative first cycle $(-\phi, 0)$, it can be returned to the first positive cycle, as shown in Eq.(19). this will return it to the first positive cycle if it is negative but has no effect if it is positive.

$$\xi'^+ = \text{mod} \left(\xi_0 + \Delta\omega_0 \frac{x_0}{v_0}, \frac{2\pi}{z} \right) + \frac{1 - \text{sign} \left(\text{mod} \left(\xi_0 + \Delta\omega_0 \frac{x_0}{v_0}, \frac{2\pi}{z} \right) \right)}{2} \phi \quad (19)$$

Eq.(19) can be substituted in Eq.(18) to have the general condition in Eq.(20):

$$0 \leq \xi'^+ \leq \Phi_b - \Delta\omega_0 \frac{x_{fed}}{v_0} \quad (20)$$

Eq.(20) can be modified to account for the case when the initial mismatch speed is negative by following the same procedure described above to derive Eq.(18). The resulted shiftability condition when the mismatch speed is negative is given in Eq.(21):

$$0 \leq \Phi_b + \Delta\omega_0 \frac{x_{fed}}{v_0} \leq \xi'^+ \leq \Phi_b \quad (21)$$

Based on that, the shiftability's dependency on certain parameters can be represented in a so-called shiftability map. The map is a 2D representation of the shifting probability, depending on two parameters, while all the others are kept constant. The first representation of a shiftability map, based on a simpler version of the shiftability condition can be found in the literature [5].

A comparison between the present model and a model from the literature [6], is shown in Figure 8. Here, the horizontal axis variable is the mismatch speed, and the vertical axis is the axial speed. The third parameter of the group of maps is the initial relative position ξ_0 . Both models gave an identical shiftability map. The turquoise color means that there is no difference between the two models: Eq.(17) and Eq.(18) are generalized shiftability conditions that apply to a particular case.

3. CONCLUSION

The correct operation of a dog teeth clutch requires a fine operating algorithm. The base of the operation is the shiftability equation that

ensures successful shifting. However, it contains many independent parameters that are often missing in the control algorithm design. Accurate dog teeth shifting helps avoiding wear and rattle noise problems.

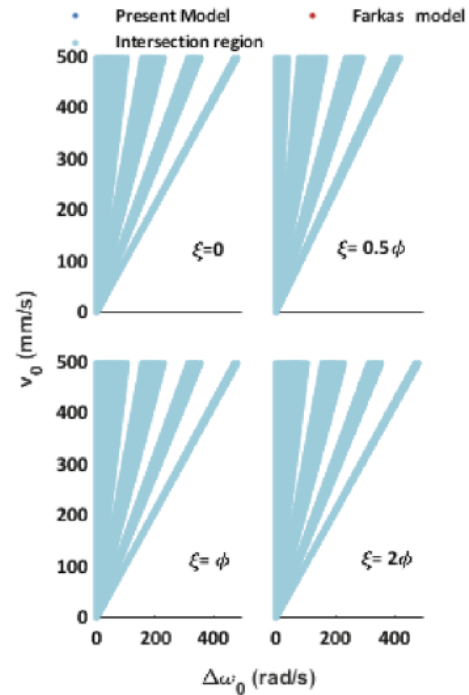


Figure 8. Shiftability condition validation

4. REFERENCES

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