KÖRMÖS TENGELYKAPCSOLÓ KAPCSOLHATÓSÁGÁNAK VIZSGÁLATA

SHIFTABILITY STUDY OF A DOG CLUTCH

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 shiftability map showing the successful engagement regions and the engagement probability, is presented based on the shiftability condition. Parameters affecting the shiftability are highlighted and angular speed to axial speed ratio is used to reduce the number of parameters. The shiftability regions are determined through analytical calculation, and the probability of the engagement is obtained for different parameters. The geometrical pattern of the shiftability regions is presented and the effect of system parameters on these regions is highlighted.

1. INTRODUCTION

In vehicle transmissions, conventional coupling elements such as the synchronizers and multi surface friction clutch (MSFC) utilize friction clutch elements to achieve successful engagement between the input and output sides. The task of the friction is to reduce the rotational speed difference between the input and output sides. Recent developments in automated manual transmissions (AMT) are focused both on mass and size reduction, which leaves little space within the gearbox casing. Without the friction elements, the dog clutch alone has high potential to fulfill the requirements compared to the conventional coupling elements [1, 2].

Moreover, the overall efficiency of heavy duty electric vehicles (EVs) can be improved by applying multi-speed gearboxes in the transmission chain [16].

Dog teeth clutch has been replacing the synchromesh because it provides quicker shifting time, has a simpler structure, and lower cost [3, 4]. However, as the mechanical speed synchronization mechanism (the friction mechanism) is missing, the speed synchronization must be a part of the gearshift control. The shifting process has to be investigated to achieve successful dog clutch engagement.

2. DOG CLUTCH SHIFTABILITY

A dog clutch is a coupling used to transmit power. It consists of two parts: the sliding sleeve and the shifted gear that have complementary geometry. These complementary shapes are referred to as dog teeth.

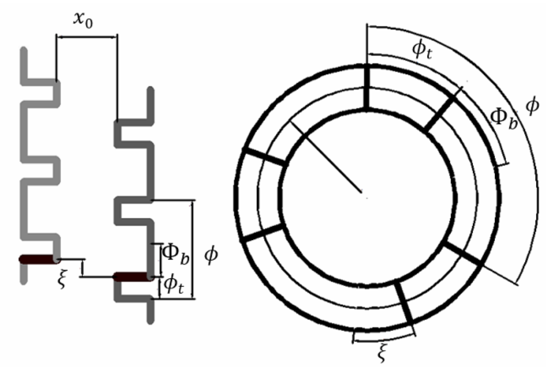


Figure 1 Dog teeth clutch geometry

The dog geometry is shown in Figure 1. At the beginning of the shifting, the sliding sleeve and the shifted gear has an axial gap x_0 and an initial relative angular position ξ_0 between the marked teeth. Figure 1b shows further parameters, where the circular teeth are represented in linear shape for the purpose of illustration. The sliding dog can slide axially with a speed v_0, while it has relative angular rotation with respect to the target gear. The relative angular rotation is called the mismatch speed $\Delta\omega_0$. The engagement of the complementary geometries is eased with an angular backlash Φ_b. The dog clutch had an angular pitch ϕ and angular tooth thickness ϕ_t.

Based on the geometry and kinematic parameters, the successful gearshift process is governed by the following expression:

$$0 \leq mod\ (\xi_0 + \Delta\omega_0 \frac{x_0}{v_0}, \frac{2\pi}{z}) \leq \Phi_b - \Delta\omega_0 \frac{x_{fed}}{v_0} \qquad (1)$$

This condition is called the shiftability condition and it guarantees such gearshift process that the complementary shapes enter directly to each other.
Let's define the ratio $q = \Delta\omega_0/v_0$, which is the angular to the axial speed ratio. The modified form of the shiftability condition is:

$$0 \leq mod\ \left(\xi_0 + qx_0, \frac{2\pi}{z}\right) \leq \Phi_b - qx_{fed} \qquad (2)$$

3. PARAMETRIC STUDY

The condition shown in eq. (2) contains six parameters listed in Table 1. These parameters are linked to the dog clutch geomtery. Our goal is to find the effect of these parameters on the dog clutch shiftability.

To study the parameter effects, the following representation is used. The speed ratio *q* range is shown in the horizontal axis of a coordinate system, while a chosen parameter range from those shown in Table 1 is represented on the vertical axis. All the other variables keep their fixed value. For each chosen variable we test the shiftability condition at discrete points (q_i, y_j) within the complete range. The succesful shifting is shown by blue dot, the unsuccesful by red dot. The obtained field is called the shiftability map (Figure 2). Here, ξ_0 was chosen for the *y* vertical axis range variable, and all other parameters remained fixed.

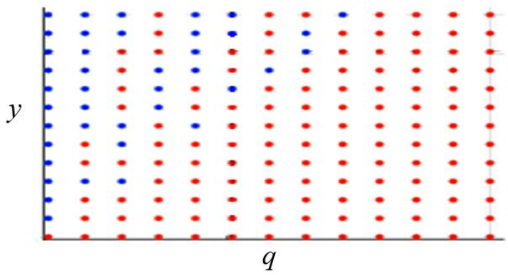


Figure 2 Example of a shiftability map

Here we can observe, that the blue dots of the succesful shifting do not form a closed homogenous field. The succesful zone looks like the branches of a plant, due to the periodic shape of the complementary geometry. We will see that the shape of the branch looking zone changes strongly upon the sudied range variable.

In fact, the initial relative position ξ_0 is considered to be a free variable, as it is difficult to measure in the gearshift process, and it has a random value in the interval $(0, 2\pi/z)$. So, the engagement process is must be handled based on probability. The engagement probability at each point (q_i ,y_j) shall be calculated according to:

$$P(y,q) = \frac{\int_0^{2\pi/z} G(q,y)d\xi_0}{2\pi/z} \qquad (3)$$

Here *G* is the shiftability condition given in Eq.(2).

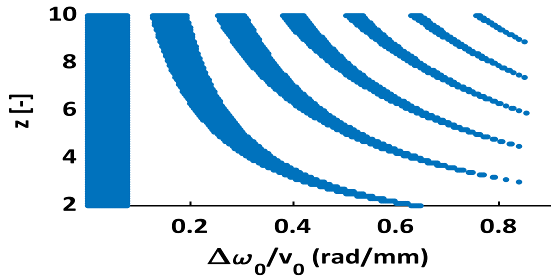
Table 1 System parameters

Parameter	Unit	Fixed Value	Range
Initial relative position ξ_0	[°]	0	Random variable
Mismatch speed $\Delta\omega_0$	[rad] ([min^{-1}])	-	-
Axial Speed v_0	[mm/s]	-	-
Number of teeth z	[-]	6	2-10
Axial gap x_0	[mm]	5	1-10
Overlap distance x_{fed}	[mm]	0.5	0.5-2
Backlash Φ_b	[°]	25	5-30
Speed ratio q	[rad/mm]	-	0-0.9

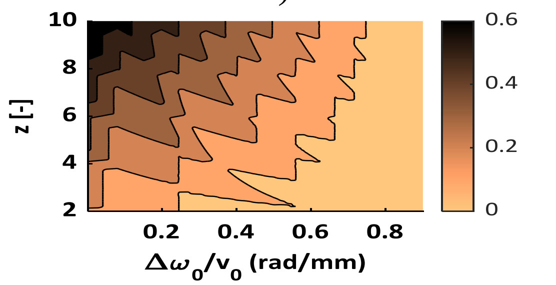
3. RESULTS

The numerical simulation results are shown in figure sets. The first figure is a 2D shiftability map, where the blue bands show the field of succesful shifting. Here, the horizontal axis shows the range of the speed ratio *q*, and the vertical axis shows the range of a selected variable. The second and eventually third figures show 3D shiftability maps where the horizontal axes are the same that in the 2D case, and the third axis is the relative angular position ξ_0. The succesful shifting volumes are shown in brown. In 2D projections of the 3D maps, the higher shifting probability zones are shown with darker shades of brown.
Figure 3 shows the engagement process sensitivity to the teeth number *z*. In Figure 3a, we can see that the teeth number has no effect on the shiftability when *q* is less than 0,8. Then, as *z* increases, the successful shifting bands got a hyperbolic shape. This shape allows the shifting in larger speed ratio zones. Figure 3b shows that the engagement probability increases with teeth

number but decreases with the speed ratio. This means that z and q have an inverse relationship, which is clear from the constant probability (or contour) lines. However, the contour lines do not have a regular shape. The increase of the tooth number z decreases the randomness level in the system since it determines the pitch, which in return defines the randomness range for the initial relative position ξ_0.



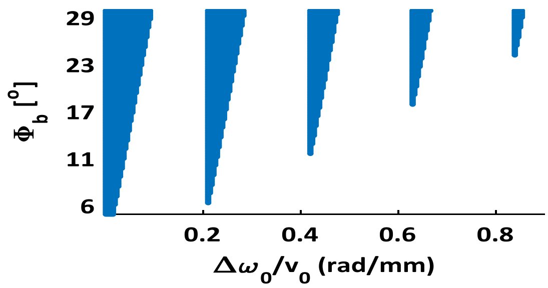
a)



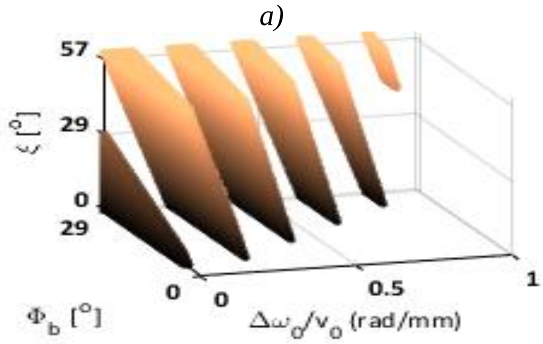
b)

Figure 3 System sensitivity to the tooth number (a) and engagement probability (b)

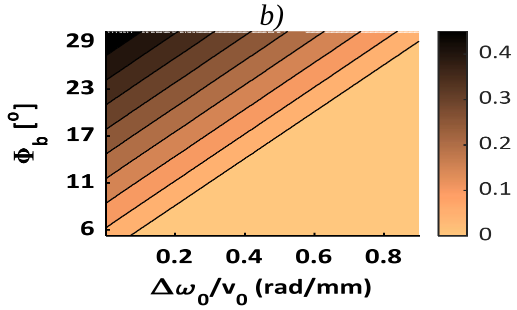
Figure 4 shows the engagement process sensitivity to the angular backlash between teeth. In Figure 4a, the shiftability bands have conical shape, opening upwards. We can see that the lower end of the bands start at higher points at higher speed ratios, and these starting points are situated along a straight line. The explanation is that at higher speed ratio, shorter time is available for the shifting, so more backlash is required for the successful engagement. In addition, this linearity is reflected in the volume representation in Figure 4b, where ξ_0 is allowed to change alongside q and y in Eq.(2) . Here the shiftability volumes are tilted towards the left (or towards lower q values) as ξ_0 increases, since a smaller gap is kept for successful engagement. Also, the volumes width increase with backlash as there is allowance for a higher q slot for successful gearshift. Figure 4c shows that engagement probability increases with the backlash, and the contour lines are linear because of the aforementioned linear relationship.



a)



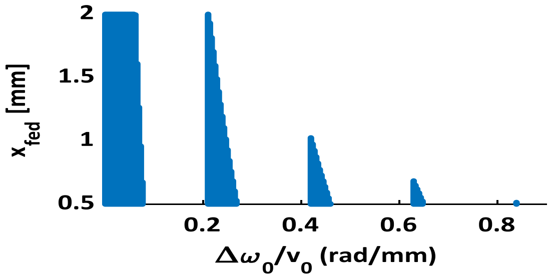
b)



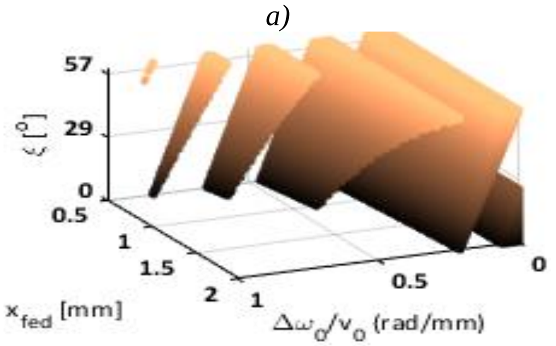
c)

Figure 4 System sensitivity to backlash (a), 3D shiftability map (b), and engagement probability (c)

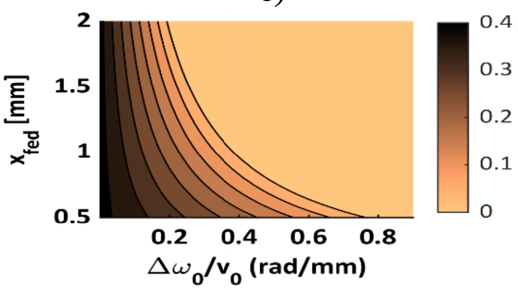
Figure 5 shows the engagement process sensitivity to the overlap distance. In Figure 5a the shiftability bands have again conical shape, with cones opening downwards. The starting point of the cones decreases with higher speed ratio. We can see that x_{fed} has an inverse effect to the backlash, since the sliding sleeve needs more time to cover a larger overlap distance. The maximum possible ratio q and the x_{fed} have an inverse relationship but it is not linear as can be seen from the starting points of the bands. This nonlinear relationship is illustrated in Figure 5b by the curved edges. Also, the length of the 3D volumes decreases as the x_{fed} increases. The length is parallel with the q axis, and this means that the succesful shift range exists till narrower q range. The probability decreases as both q and x_{fed} increase and the constant probability lines confirm the nonlinear inverse relationship between x_{fed} and q.



a)



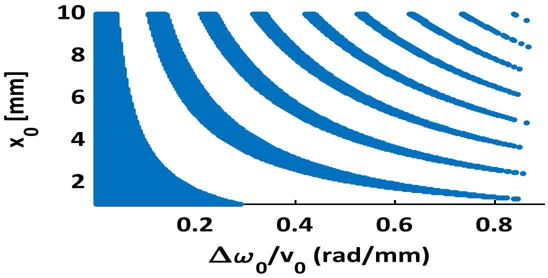
b)



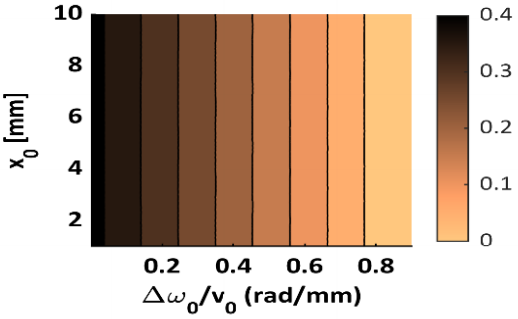
c)

Figure 5 System sensitivity to overlap distance (a), 3D shiftability map (b), and engagement probability (c)

Figure 6 shows the engagement process sensitivity to the axial distance between the parts at the beginning of the shifting. We can see that here again, the bands have hyperbolic shape. We can also see, that below the *q* value of *0.3* the shifting is succesful. Figure 6b, shows that the probability constant lines are parallel to the axial gap axis which means it does not affect the engagement process. In fact, this is an expected outcome, since the change in x_0 changes the time to cover the gap. The size of x_0 in the system is directly proportional to the time duration to cover the gap. The end of the gap position becomes the initial relative postion in studying the shiftability. We can see that the engagement probability is more connected to the overlap distance, since, besides the realtive postion and the mismatch speed, it identifes if the sleeve and the gear will impact during the overlap distance coverage.



a)



b)

Figure 6 System sensitivity to axial distance (a) and engagement probability (b)

4. CONCLUSION

The successful shifting of a dog clutch depends on many factors. Due to the periodic nature of the geometry, zones of the successful shifting are often distinct, and their shape depends extremely on the actual parameter values. Thus, it is almost impossible to find them by try and error. To elaborate a quick and efficient shifting control algorithm based on measured parameters, the use of the shiftability condition is necessary.

5. REFERENCES

[1] A. Dick, J. Greiner, A. Locher, F. Jauch, Optimization potential for a state of the art 8-Speed AT, SAE Int. J. Passenger Cars Mech. Syst. 6(2013-01-1272) (2013) 899-907.

[2] P. Echtler, M. Mileti, A. Damm, TorqueLine-Konische Kupplung mit Formschluss als alternatives Schaltelement für Automatikgetriebe, VDI-Fachtagung Kupplungen und Kupplungssysteme in Antrieben, Ettlingen (2017).

[3] I. Shiotsu, H. Tani, M. Kimura, Y. Nozawa, A. Honda, M. Tabuchi, H. Yoshino, K. Kanzaki, Development of High Efficiency Dog Clutch with One-Way Mechanism for Stepped Automatic Transmissions, Int. J Automot. Eng. 10(2) (2019) 156-161.

[4] D.T. Vierk, S.J. Kowal, Composite friction and dog clutch, US Patent 10,060,485, 2018.