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Design of Synchronizer

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Abstract -*Today, synchronizers are used in all manual transmissions including trucks and commercial vehicles. Most synchronizing systems are patented or covered under copyright act. Little technical information is available in public domain.The manual transmission synchronizer design has been a real challenge and is usually referred to as a myth and black magic. A mathematical algorithm and dimensioning and tolerancing scheme has been developed to dispel this myth. The paper attempts to demonstrate the fact that the calculations of synchronizer physical parameters should be supported by Sopacticated dimensioning and tolerancing the components design to achieve the intended functional objective. A mathematical algorithm is developed which facilitates establishing the sleeve and blocker ring pointing angle relationship with the synchronizer size, coefficient of friction, cone torque, and index torque. The relationship is presented graphically in a unique manner identifying the clash and hard shift zones. As such, it allows sizing the synchronizer and selection of the parameters for a given application for comfortable shift ability between the two extremes of clash and hard shift.*

Keywords*- synchronizer, coefficient of friction, synchronizer size, index torque, cone torque, Chamfer Angle.*

I. INTRODUCTION

In a synchromesh transmission a synchronizer is a friction clutch which synchronizes the rotational speed of the transmission output shaft and the gear to be engaged allowing smooth gear change. The location of synchronizers is much heeded to minimize the effect of system inertia and relative speeds of the rotating components. Increasing trend towards higher engine power and higher engine speeds due to multi valves per cylinder have resulted in higher shift efforts. Concurrently, the driver still demands smooth shiftability. These conflicting expectations require greater efficiency from the synchronizer design.

Generally, in order to meet these conflicting expectations larger size synchronizers as well as multicone synchronizers are packaged on the shafts to do more work in a given time. However the basic design of the synchronizer and its components has remained an excruciating challenge. Synchronizer technology is a myth and the essence of smooth shifting transmission is shrouded therein. It must be recognized that synchronizer endures incessant punishment, more so than any other transmission components, and is expected to continue to work flawlessly for the life of the vehicle. Additionally, the driver abuse adversely affects the synchronizer performance eventually resulting in malfunction.

II. OBJECTIVE

1.To modify friction ring of synchronizer .
2.To CAD drawing of friction ring with CREO.
3.To desing Hub and Sleeve of synchronizer.
4.To study the reverse engineering and modified synchronizer.

III. **Significant Parameters**: Algorithms and Nomograms

Listed below are significant physical parameters that are crucial to the synchronizer design for satisfactory compliance with the functional objectives:

3.1Break Through Load (BTL) and Proximity: Also known as push through load, BTL effectively sets the blocker ring into block position. The BTL should start to build as soon as the applied force at the sleeve initiates its movement and should stay on until the
sleeve tooth contacts the blocker ring tooth. This axial distance from sleeve tooth pointing to the blocker ring tooth pointing contact is called proximity and is dealt at length in the dimensioning and tolerancing section. BTL drop off prior to the contact point will unload the
blocker ring too soon interrupting oil wiping action resulting in gear clash.

On the other hand BTL continuing beyond the contact point will cause ring sticking. BTL is a function of detent spring rate, strut bump or ball height, coefficient of friction between detent ball and the sleeve, and the ramp angle of the annulus groove in the sleeve. Mathematically analyzing the forces on one of the three strut detents, BTL can be calculated from the following derivations:

As shown in Figure 1, taking sum of forces on the sleeve in x- and y-direction

taking sum of forces on ball

$F_A = N_S \, Sin\theta + f_S \, Cos\theta$

$F_S = \mu Ns$

$$F_A = N_S \, (Sin\theta + \mu \, Cos\theta) \qquad (1)$$

taking sum of forces on ball

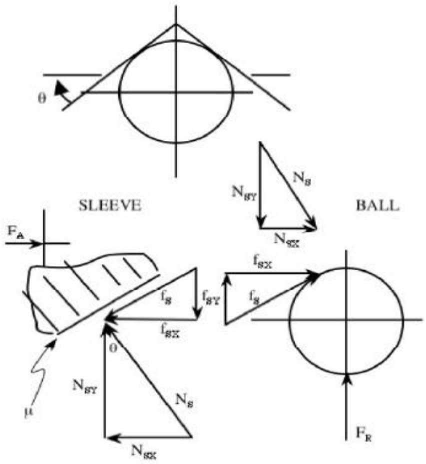

Figure 1: BTL – Free Body Diagram

$F_A = Ns \, Sin\theta + fs \, Cos\theta$

$= Ns \, Sin\theta + \mu Ns Cos\theta$

$F_R + fs Sin\theta = Ns Cos\theta$

$$F_R = Ns \, (Cos\theta - \mu Sin\,\theta) \qquad (2)$$

Substituting for Ns from equations (1) in equation (2),

$$F_R = F_A \frac{Cos\theta - \mu \, Sin\theta}{Sin\theta + \mu Cos\theta}$$

$$F_A = F_R \frac{Sin\theta + \mu Cos\theta}{Cos\theta - \mu Sin\theta}$$

$$= F_R \frac{\mu + Tan\,\theta}{1 - \mu Tan\theta} \qquad (3)$$

$BTL = 3\times F_A$

$$= 3\times F_R \, \frac{\mu + Tan\theta}{1 - \mu Tan\theta}$$

By magnitude the BTL should be smaller than the axial force applied at the sleeve groove, and too low could create clash condition.

3.2 Cone Torque: As the blocker ring pushes axially on to the cone the oil is wiped out and friction force is generated in the direction of the cone angle between the cone and friction surfaces. The cone torque is primarily a function of the axial force applied to the sleeve, the cone angle, the surface coefficient of friction, and active cone diameter. Cone torque can be calculated from the following equation, refer **Figure 2**:

$$T_C = \frac{F\times\mu_c\times R}{Sin\alpha} \qquad (4)$$

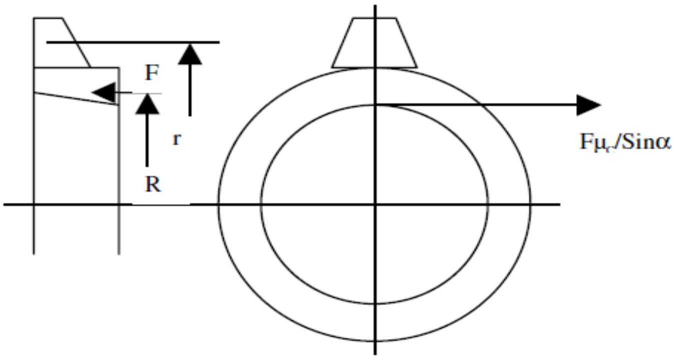

Figure 2: Cone Torque – Free Body Diagram

The cone torque is countered by the index torque, and cone torque must be greater in magnitude to overcome the torque due to ring indexing force and complete synchronization successfully,

$$T_C \geq T_I \tag{5}$$

3.3 Index Torque: When the synchronizer ring is indexed and the sleeve has traversed the proximity distance the sleeve pointing contacts the blocker ring pointing and a friction force is generated between the two chamfers. This friction force is in the direction of pointing angle resulting in torque which is known as index torque. The index torque is a function of axial force applied to the sleeve, the tooth pointing angle, the pitch diameter of the blocking teeth, and surface coefficient of friction between the tooth pointing surfaces of sleeve and blocker ring. The index torque can be calculated from the following derivations, refer Figure 3:

$T_I = F_I \times r$

summation of forces in x-direction on sleeve:

$$F_I = N_S \cos\beta - f_S \sin\beta$$
$$= N_S(\cos\beta - \mu_P \sin\beta)$$

summation of forces in y-direction on sleeve:

$$F = N_S(\sin\beta + \mu_P \cos\beta) \tag{6}$$

$$N_S = \frac{F}{(\sin\beta + \mu_P \cos\beta)}$$

$$F_I = F\frac{(\cos\beta - \mu_P \sin\beta)}{(\sin\beta + \mu_P \cos\beta)}$$

$$T_I = F \times r \frac{(\cos\beta - \mu_P \sin\beta)}{(\sin\beta + \mu_P \cos\beta)}$$

$$= F \times r \frac{1 - \mu_P \tan\beta}{\mu_P + \tan\beta}$$

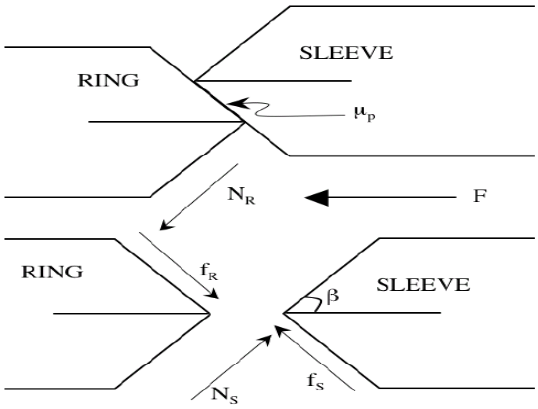

Figure 3: Index Torque – Free Body Diagram

In the inequality (5) substituting for T_C from (4) and for T_I from (6), we get

$$\frac{F\times\mu_C\times R}{\sin\alpha} \geq F\times r\,\frac{1-\mu_P\tan\beta}{\mu_P+\tan\beta} \qquad (7)$$

It can be observed that the inequality above has four interdependent significant synchronizer parameters. Treating this as an equation nomograms have been developed to help size, select, and verify the parameters of synchronizer for a given application.

IV. DESIGN PROCESS:

After selecting the physical parameters of the synchronizer namely sleeve and blocker ring pointing angle, cone angle, cone coefficient of friction, and the size, the very critical step is to design, dimension, and tolerance the synchronizer components. The intended objective of the design process should be to dimension and tolerance the individual components in a manner such that along with the selected parameters the functional objectives are achieved satisfactorily. The process consists of charting the synchronization events, and iteratively dimensioning, stacking, and tolerancing for the best results. The synchronization episode has been broken up into following distinct events:

4.1 Event I: Strut Contacts Blocker Ring – This is the starting point of break through load (BTL) and strut loading. What is also called zero (0) point will be the first contact of the strut on the ring. The zero point implies maximum strut length, maximum ring lug thickness, and maximum gage point offset. On the other extreme, the last contact point implies minimum strut length, minimum ring lug thickness, and minimum gage point offset. Hence the total differences are:

Max – Min strut length = ($L_{ST\ max}$ - $L_{ST\ min}$)
Max – Min ring thickness = (L_{RMax} - L_{RMin})
Max – Min gage point = (G_{Max} – G_{Min})
Taking first contact point as zero point the last contact will occur at a distance
($L_{ST\ Max}$ – $L_{ST\ Min}$) + (L_{Rmax} – L_{Rmin}) + (G_{Max} – G_{Min})(9)

The event is pictorially illustrated in Figure 4. The strut loading starts at the point of first contact, and earlier the loading begins the better. The components involved in this event are sleeve, detent strut/ball, detent spring.

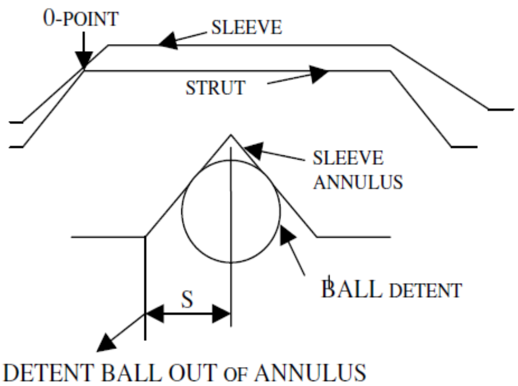

Figure 4: First Contact, Sleeve to Strut

4.2 Event II: Sleeve Tooth Chamfer Through Gear Clutching Tooth Chamfer

This is the final event when the sleeve travels from the zero position, and its chamfer passes the gear clutching tooth chamfer to complete the gear engagement. During this event the blocker ring is completely unloaded and freely gets back to zero position marking the end of cone torque. The total distance traveled by sleeve pointing from zero position to go past the gear clutching tooth chamfer can be computed as follows: Refer to Figure 4, section B-B,

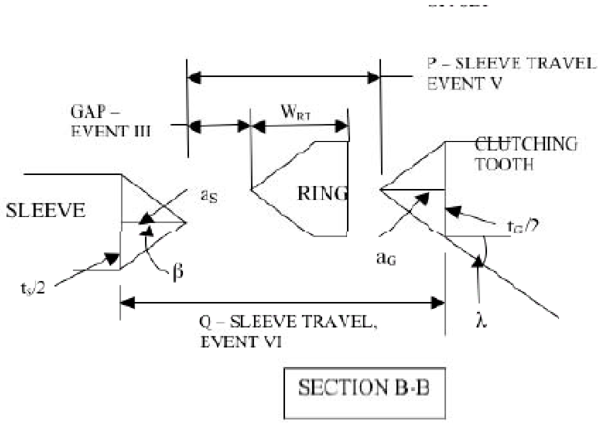

Figure5: Distance P, Sleeve Tooth Pointing to Clutching Tooth Pointing

$$a_S = \frac{t_S}{2\tan\beta}$$

$$a_G = \frac{t_G}{2\tan\lambda}$$

V. Conclusions

1. The mathematical algorithm can be used to establish accurate relationship among the synchronizer significant physical parameters: coefficient of friction, synchronizer size, cone torque, cone angle, index torque, and sleeve/blocker ring pointing angle.
2. The nomograms aid in viewing significant physical parameters relationship instantly.

VI. Nomenclature

AL	Arc length
a	½ detent groove width at gage point
a_R	X-coordinate of ring pointing angle
a_S	X-coordinate of sleeve pointing angle
a_G	X-component of gear clutching tooth pointing
BTL	Break through load
C_T	Gear back face to clutching tooth front face
D	Minor dia sleeve splines
D_G	Gage dia sleeve detent ramp
D_P	Pitch dia ring/sleeve tooth
D_t	Outer dia ring tooth
F	Axial force sleeve Groove
F_A	Axial load to overcome detent spring reaction
F_R	Reaction force, detent spring
F_I	Indexing force
f_R	Friction force, ring
f_S	Friction force, sleeve
G	Gage point offset
L_B	½ strut bump length
L_R	Ring lug width, axial
L_{RW}	Total ring width
L_{SL}	Length, sleeve front face to rear gage point
L_{ST}	½ strut length
N	Number of ring teeth/sleeve spaces
N_R	Normal force, ring

N_S	Normal force, sleeve
N_T	Number of sleeve teeth
P	Sleeve tooth point to clutching tooth point from zero point
Q	Sleeve tooth chamfer to clutching tooth chamfer from zero point
R	½ cone gage dia
r	½ pitch dia sleeve/ring tooth
r_R	Ring radius
r_S	Radius at slot for ring lug in sleeve
S	Sleeve tooth point to ring tooth point from '0'
T_C	Cone torque
T_I	Index torque
t_G	Gear clutching tooth width
t_R	Ring tooth width
t_S	Sleeve tooth width
t_t	ring tooth width at ring OD
t_{DP}	Ring tooth width at pitch dia
W_L	Ring lug width
W_S	Hub slot width
W_{RT}	Ring tooth thickness, axial
X	X-component of sleeve ramp angle
Y	Y-component of sleeve ramp angle
Z	½ sleeve detent groove width
α	Cone angle
α_{SLOT}	Angle at any side of hub slot
β	POINTING angle, sleeve/ring
γ	Angle at any side of lug
δ	Distance, cone gage point to front of clutching tooth
θ	Sleeve detent ramp angle
λ	Clutching tooth pointing angle
μ	Coefficient of friction, detent strut/ball to sleeve
μ_C	Coefficient of friction, cone surface
μ_l	Locking Coefficient, sin α
μ_p	Coefficient of friction, sleeve to ring pointing
ψ	Ring clocking angle
φ_{PA}	Pressure angle, ring/sleeve
φ_t	Transverse pressure angle

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