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Effects of kinematic viscosity of grease on efficiency of a planetary gearbox.

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ABSTRACT

The objective of this work is to evaluate analytically the effect of kinematic viscosity of grease on efficiency performance of gearbox. A planetary gearbox with outer diameter 32mm and gear ratio 5.75 is employed for the test. The major losses of the gearbox are mathematically modelled. The result extracted showed that the efficiency is greatly affected by the sliding friction. It was found analytically that the viscosity of the grease used plays a major role in controlling sliding friction and thus can affect efficiency if not selected properly. Various types of grease with different kinematic viscosity are tested against the efficiency using Drozdov and Gavrikov equation to calculate co efficient of friction. It was observed that the change in grease used leads to the change in efficiency of the gearbox, the results are plotted graphically.

KEYWORDS Planetary gearbox, Kinematic viscosity, Efficiency, coefficient of friction.

Introduction:
Epicyclic gear or more commonly named planetary gear is a form of gear setup typically used in applications where high gear ratio and/or small dimensions are sought after. The gearbox in this paperuses a four wheel design implementing four planetary gears in four stages.A single stage can achieve a ratio of approximately 5.75, although sometimes an even higher ratio is required. In order to achieve this higher ratio two or more stages can be paired in an enclosure creating a gearbox with variable gear ratio and axis rotational direction.

Fig 1: planetary Gearbox Internal view.

Locking the ring wheel and using the sun wheel as input creates as mentioned in the table above a down shift action with the sun gear having to do multiple turns for the planet carrier to do one. Using the formula in the table the outgoing axial rotation is given by.

ws = speed of sun gear

wc = speed of carrier

R = no. of teeth on ring gear

S = no. of teeth on sun gear

$$\frac{\omega s}{1+R/S} = \omega c (1)$$

Since the ratio is listed as 5.75 in this example, the incoming sun wheel will have to do 5.75 rotations for the outgoing planet carrier to do one.

Points of extra interest:

- What are the total gearbox losses?
- What is individual gear mesh loss?
- What role the Lubricant plays?
- How kinematic viscosity affects the efficiency of the gearbox?

2. Mechanical Losses:
The mechanical losses of the gearbox can be divided into different sub losses. These sub losses are:

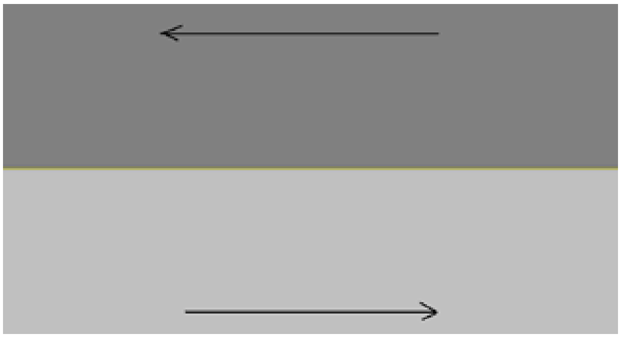
- Sliding losses
- Rolling losses
- Wind age losses
- Gear bearing losses

2.1 Sliding losses:
The sliding loss of a spur gear pair is attributed to the sliding between tooth surfaces during meshing that lead to the friction force along the tooth profile direction. To estimate the sliding loss, firstly the sliding loss of the single tooth meshing is considered, and then the sliding loss during double teeth meshing is determined by combining the sliding loss of single tooth meshing together according to the meshing order.

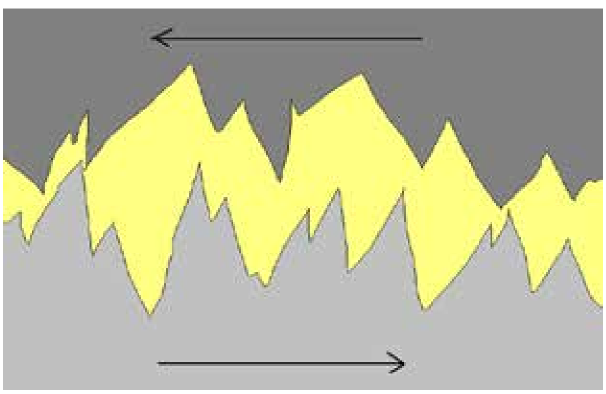
The power loss due to friction is given by: $Fs(x) = \mu_s(x) .w_s(x)$ (2)

Calculation for overall losses			
Sr no.	Losses type	Symbol	Value
1	Sliding Losses, W	Qs	0.0134
2	Rolling Losses, W	Q_R	0.0276
3	Windage Losses (for Pinion), W	Qwp	0.00027
4	Windage Losses (for Gear), W	Qwg	0.00030
5	Gear mesh Losses, W	Qm	0.33302
6	Bearing Lossses, W	Q_B	0.00643
7	Total Losses, W	Q_{total}	0.339
8	Efficiency of gear mesh	Eff.	89.87%

Table 1: Calculation of overall losses in gearbox



Macro level



Micro level Micro level

Fig 2: surface roughness on different levels.

2.2 Rolling losses

When two lubricated cylinders roll against each other a rolling loss is generated from the pressure build up in the lubricant as it is squeezed in between them. In the sliding losses section it is shown how important it is to ensure that the friction is in the fluid stage. To make sure the contact is fluid the gear designers use a lubricant with high enough viscosity. The pay off from this is the rolling forces gets bigger. Just like the sliding losses the formula used to calculate this loss are developed by Anderson &Loewenthal (Anderson &Loewenthal, 1980). Analyzing their result it is given that the rolling loss is somewhat load independent mainly depending upon the rolling velocity. The rolling force is given by the equation:

$F_r (x) = C_2. hR(x) . f_w$(3)

Where F_r is the rolling force, h_R the fluid film thickness multiplied with a thermal reduction factor. The factor is developed to decrease the film thickness at high pitch line velocities for the heating created by lubrication inlet shear. In this paper the thermal factor is set to 1 since adequate data to develop the correction factor is missing.$f_w$is the normal force acting on the tooth.Various calculations for efficiency were made on the basis of the theoretical data obtained and the losses considered.

The pie chart below shows what percentage of power loss is accounted for which type.

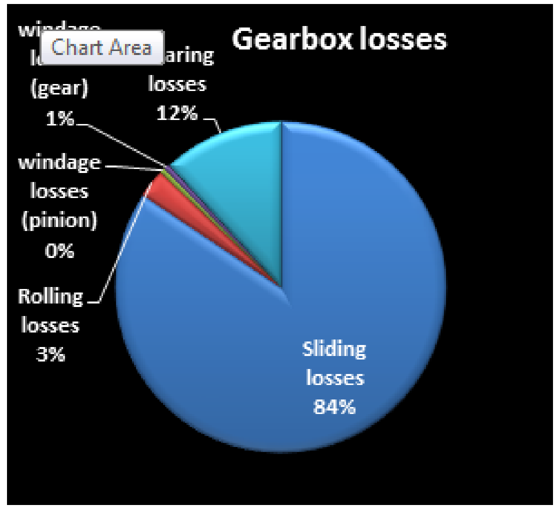


Fig 3: percentage of loss shared by the type of losses

The pie chart shows that the Efficiency is mostly affected by gear mesh losses, and the gear mesh losses are mainly depend on the sliding losses. The factors that sliding losses depend on are co efficient of friction, surface roughness kinematic viscosity of the grease used, etc.From the calculations it is found that the sliding friction loss is proportional to the co efficient of friction.

2.3 Friction Coefficient:

To calculate the sliding loss in Eq. (2), the value of the friction coefficient must be known. Because many parameters such as rolling and sliding velocity, viscosity of the lubricant, surface roughness and loading condition affect significantly the friction coefficient, the value of friction coefficient must be used to suit with these parameters. There are many researches proposed the empirical formulas for estimation of the friction coefficient. These formulas are constructed base on the curve fitting of the results obtained from such twin-disk experiments, and are shown in Table 2. In these formulas, vkand voare kinematic and dynamic viscosities of lubricant, Vs is the relative sliding velocity, Vris thesum of the rolling velocities,Pmax is the maximum contact pressure andφ is the sliding loss ratio.

Because these formulas had been constructed experimentally, they have restrictions according to their base experimental conditions. To use these formulas, input parameters in the calculation that are the values of lubricant parameters, surface roughness parameters, and operating parameters are previously checked carefully to assure that these formulas are applicable. The empirical formulae used to calculate friction coefficient is given by Different publishers are as follows:

Empirical Formulae	Published Author
μ = [0.8 + Vr φ + 13.4]-1 φ = 0.47 – 0.13 (10)-4Pmax - 0.4(10)-3	Drozdov and Gavrikov
μ = 0.0127 [ ] Log10	Benedictand Kelley

μ = 0.325	ISO TC 60

Table 2: Formulae for coefficient of friction by different authors.

The estimated results calculated by using the friction coefficient formula proposed by Drozdov and Gavrikov are the most accurate comparing with the experimental results.

3.Lubrication:

Gearboxes are lubricated with either grease or oil. Many variations of grease and oil exist with qualities such as: high temperature, low temperature, extreme pressure, water resistance, corrosion protection, etc. Lubrication is one of the most important components of a gearbox. Lubricant has two main purposes to serve. It keeps components from wearing and also keeps them cool. Most gearbox failures can be attributed to improper lubrication. Viscosity is a key attribute of the gear lubricant (grease in this case). The proper oil viscosity will provide an oil film between meshing gear teeth. This oil film is very thin and keeps the gear teeth from actually contacting each other. With too thin of a film or no film, failures such as scoring or wear will occur. By using grease KluberBarrierta L 55/2 the efficiency calculated for the planetary gearbox is approximately 89%. Seven different Greases are compared on the basis of their kinematic Viscosity and the graph is plotted against the efficiency (for first stage).Various greases with different kinematic viscosity have been taken , and calculation of friction coefficient is carried out keeping all other factors and losses constant. The following graphs were plotted on the basis of obtained values.

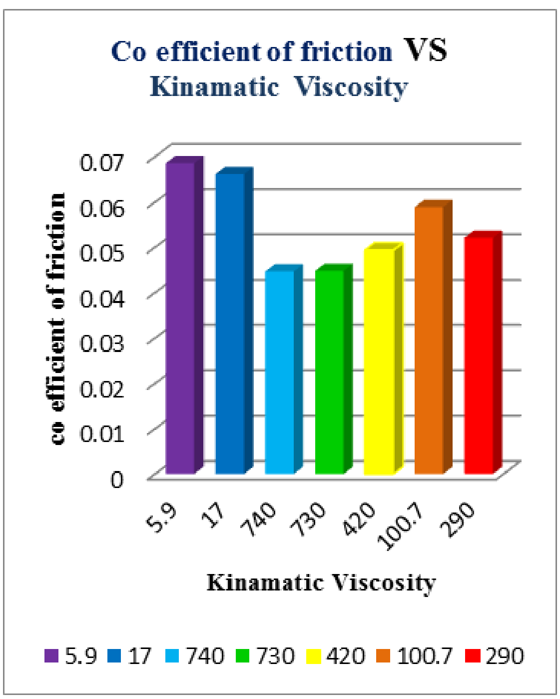


Fig 4.Kinematic viscosity Vs coefficient of friction.

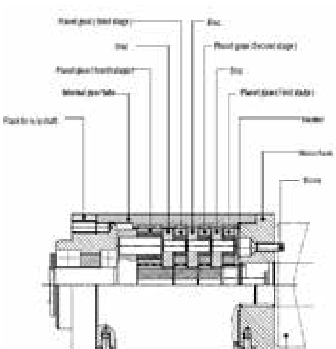


Fig 5. cut section of a four stage planetary gearbox

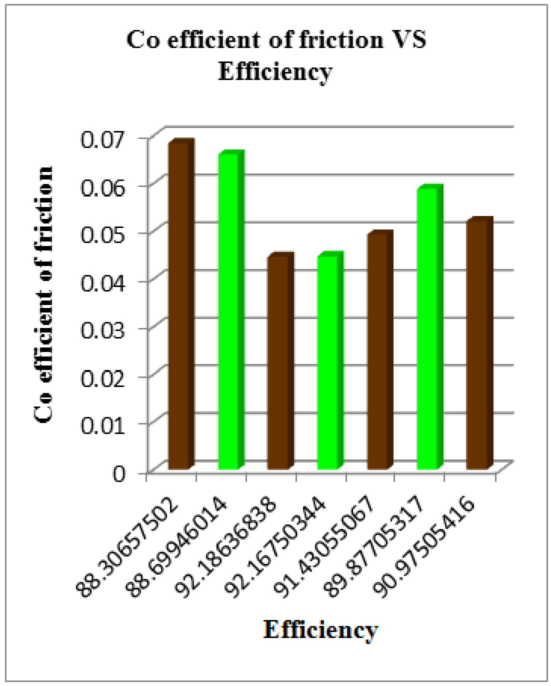


Fig6 : Efficiency Vs Coefficient of friction

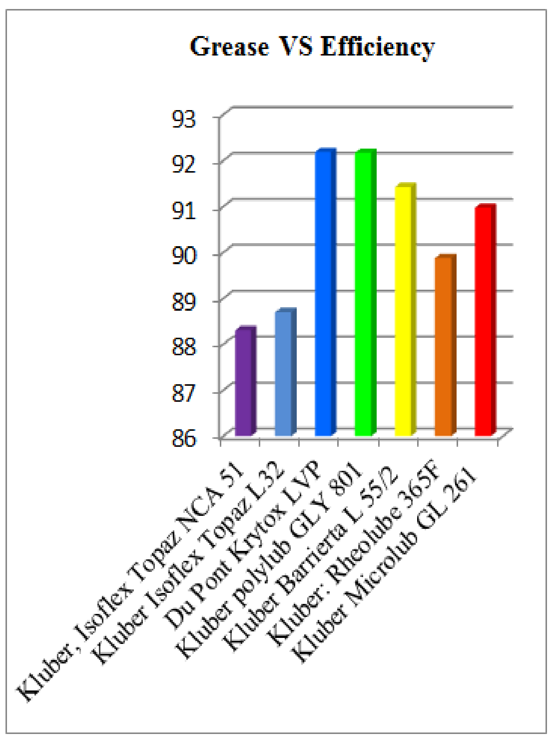


Fig 7: Grease used Vs Efficiency

4. Conclusion:

The effects of gear parameters and operating conditions on the sliding loss of a spur gear pair have been investigated analytically. The sliding losses increase with increasing coefficient of friction. The gear pair with larger friction coefficient has higher loss than the gear pair having small friction coefficient. The co efficient of friction in turn depends on the kinematic viscosity of the grease used. Small pressure angle gear pair has larger sliding loss, and increasing of gear ratio also increase the sliding loss. The estimated results agree well with the experimental results. The use of friction coefficient formula proposed by Drozdov and Gavrikov in calculation brings the most accurate results. From the graphs above it can be concluded that the grease Du point krytox LVP has the best performance in terms of efficiency, as the kinematic viscosity of the same is the highest i.e. 740 mm2/s among all the greases taken for the comparison.

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