Volume : 2 | Issue : 8 | Aug 2013 • ISSN No 2277 - 8160

Research Paper | Engineering

Investigation of Spin Power Losses in Single Stage Spur Gear System Using Matlab

Vijay Kumar Karma | Assistant Professor, IET-DAVV, Indore

Ram Kumar Soni | PG Student, IET-DAVV, Indore

ABSTRACT *In this paper, the influence of operating parameters such as speed, viscosity and density is analyzed on the spin power losses and it is investigated theoretically and the theoretical analysis is done for an already made test set up. To perform theoretical investigation some empirical formulae have been used. The spin power losses are analyzed for low operating speeds. Analysis of power loss data revealed that all operating parameters influence the types of spin transmission power loss significantly and specific conclusions were drawn in order to aid attempts to decrease power losses. The theoretical database formed as a result of this study is extensive to allow the complete validation of transmission power loss models.*

KEYWORDS: gear, churning power loss, windage power loss

INTRODUCTION
Gears have always been a popular research topic since it is well used in many mechanical systems like as transmission systems and industrial applications. Most researchers are analyzing about the influence of most important contributing factor in the power loss. [1],[2]The power losses can be divided into load dependent (mechanical) losses and load independent (spin) losses.

Sources of load independent (spin) power loss include:
- Oil churning losses
- Air windage losses

Load dependent (mechanical) losses are composed of:
- Rolling losses
- Sliding losses

OBJECTIVE:
- Comparison of churning power loss for two different lubricating oils with the variation of speed.
- Comparison of windage power loss for two different lubricating oils with the variation of speed.

METHODOLOGY:
In this analysis data of a test rig is used to do the power loss analysis. The calculations are done using MATLAB software.

THE SPECIFICATIONS OF THE GEARS ARE:
TABLE – 1

Properties	Gear 1	Gear 2
No. of teeth	32	35
Face width	13mm	13mm
Outer diameter	58.8mm	66.49mm
Addendum + dedendum	4.22mm	4.22mm
Module	1.96mm	1.96mm
Pitch circle diameter	56.84mm	64.5mm
Pressure angle	20˚	20˚

SPECIFICATIONS OF USED LUBRICANT ARE:
TABLE - 2

Type of lubricant	Density (kg/m^3)	Kinematic viscosity (cSt) at 40^0C	Kinematic viscosity (cSt) at 100^0C
SAE 30	885	100	11.3
SAE 40	897.1	160.8	15.2

Used empirical formulas are:
Model of bones [2][3] for churning power loss:

$$P_{churning} = \frac{1}{2} \cdot C_m \cdot \rho \cdot \omega^3 \cdot S_m \cdot r^3 \qquad (1)$$

With S_m : Surface area in contact with the gear

For laminar flow Re < 2000

$$C_m = \frac{20}{Re} \qquad (2)$$

For intermediate flow regime 2000 < Re < 100000

$$C_m = 8.6 \cdot 10^4 \cdot Re^{1/3} \qquad (3)$$

For turbulent flow Re > 100000

$$C_m = (5 \cdot 10^8) / Re^2 \qquad (4)$$

Here

C_m: Constant based on flow regime

ρ: lubricant density

ω: angular velocity of spur gear

ω=2πN/60

r: pitch circle radius

Re: Reynolds number

Re= v.l/υ

v: rotational speed

v= r.ω

l: immersion depth

υ: kinematic viscosity

Model of lord [4] for windage power loss:
For module 1.25-4

$$P_{windage} = 2.9 \cdot \rho \cdot \omega^3 \cdot r^{3.51} \cdot m^{1.06} \cdot b^{0.42} (5)$$

Here the notation of all variables is same as churning power loss.

Some extra variables are:
m: module
b: gear width

CALCULATIONS:
Two cases are taken as case study 1 and case study 2.

Case study 1: Comparison of churning power loss for two different lubricating oils with the variation of speed:

For gear in SAE30
N=[0:30:150] % speed in rpm

D=0.0645 % pitch circle dia. in meters

v=100*10^(-5) % kinematic viscosity at 40 degree Celsius

l=0.06649 % immersion depth, fully dipped condition so depth will be outer dia.

Re= (((pi*D.*N)/60)/v)*l % Reynolds no

Cm=20./Re

Sm=0.0199 % surface area in contact with the gear in fully dipped condition

d=885 % density of lubricant

r= 0.03225 % pitch circle radius

w=(2*pi.*N)/60 % angular velocity

Pchurning=0.5.*Cm*d.*(w.^3)*Sm*(r^3)

For pinion in SAE30
N=[0:30:150] % speed

D=0.05685 % pitch circle dia.

v=100*10^(-5) % kinematic viscosity at 40 degree Celsius

l=0.0588 % immersion depth, fully dipped condition so depth will be outer dia.

Re= (((pi*D.*N)/60)/v)*l % Reynolds no

Cm=20./Re

Sm=0.0132 % surface area in contact with the gear in fully dipped condition

d=885 % density of lubricant

r= 0.028425 % pitch circle radius

w=(2*pi.*N)/60 % angular velocity

P1churning=0.5.*Cm*d.*(w.^3)*Sm*(r^3)

P2churning=Pchurning+P1churning

P2churning=[0 0.0430 0.1721 0.3873 0.6885 1.0758]

SAE30=[0 0.0430 0.1721 0.3873 0.6885 1.0758]

For gear in SAE40
N=[0:30:150] % speed in rpm

D=0.0645 % pitch circle dia.

v=160.8*10^(-5) % kinematic viscosity at 40 degree Celsius

l=0.06649 % immersion depth, fully dipped condition so depth will be outer dia.

Re= (((pi*D.*N)/60)/v)*l % Reynolds no

Cm=20./Re

Sm=0.0199 % surface area in contact with the gear in fully dipped condition

d=897.1 % density of lubricant in

r= 0.03225 % pitch circle radius

w=(2*pi.*N)/60 % angular velocity

Pchurning=0.5.*Cm*d.*(w.^3)*Sm*(r^3)

For pinion in SAE40
N=[0:30:150] % speed in rpm

D=0.05685 % pitch circle

v=160.8*10^(-5) % kinematic viscosity at 40 degree Celsius

l=0.0588 % immersion depth, fully dipped condition so depth will be outer dia.

Re= (((pi*D.*N)/60)/v)*l % Reynolds no

Cm=20./Re

Sm=0.0132 % surface area in contact with the gear in fully dipped condition

d=897.1 % density of lubricant

r= 0.028425 % pitch circle radius

w=(2*pi.*N)/60 % angular velocity

P1churning=0.5.*Cm*d.*(w.^3)*Sm*(r^3)

P2churning=Pchurning+P1churning

P2churning =[0 0.0701 0.2806 0.6313 1.1223 1.7536]

SAE40=[0 0.0701 0.2806 0.6313 1.1223 1.7536]

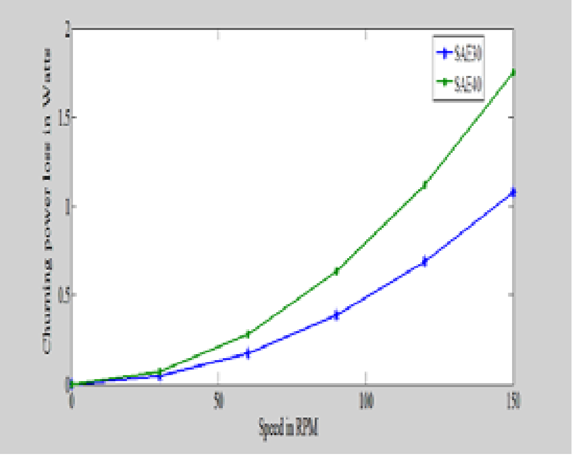

Figure 1: graph of comparison of churning power loss

Here with the rise of speed churning power loss increases and in this graph slope of churning power loss increases with the rise of speed. In this graph with the rise of density and viscosity churning power loss increases.

Case study 2: Comparison of windage power loss for two different lubricating oils with the variation of speed:
For gear in SAE30
d=18.72
N=[0:30:150]
w=(2*pi.*N)/60
r=0.03225

```
m=1.96
b=0.013
Pwindage=2.9*d.*(w.^3)*(r^3.51)*(m^1.06)*(b^0.42)
```

For pinion in SAE30

```
d=18.72
N=[0:30:150]
w=(2*pi.*N)/60
r=0.028425
m=1.96
b=0.013
Pwindage1=2.9*d.*(w.^3)*(r^3.51)*(m^1.06)*(b^0.42)
Pwindage2=[Pwindage+Pwindage1]
Pwindage2=[0 0.0053 0.0424 0.1430 0.3391 0.6623]
```

For gear in SAE40

```
d=18.96
N=[0:30:150]
w=(2*pi.*N)/60
r=0.03225
m=1.96
b=0.013
Pwindage=2.9*d.*(w.^3)*(r^3.51)*(m^1.06)*(b^0.42)
```

For pinion in SAE40

```
d=18.96
N=[0:30:150]
w=(2*pi.*N)/60
r=0.028425
m=1.96
b=0.013
Pwindage1=2.9*d.*(w.^3)*(r^3.51)*(m^1.06)*(b^0.42)
Pwindage2=[Pwindage+Pwindage1]
Pwindage2=[0 0.0054 0.0429 0.1449 0.3434 0.6708]
```

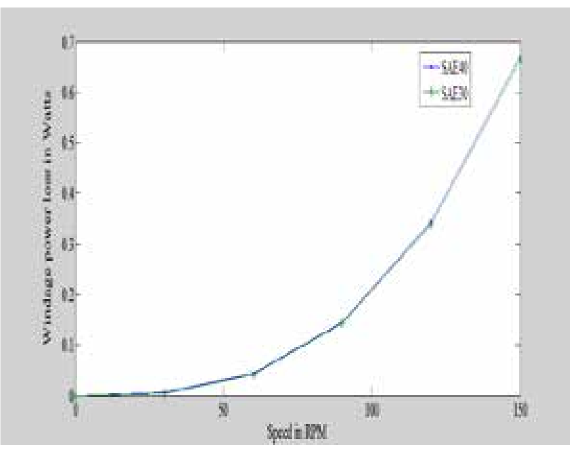

Figure 2: graph of comparison of windage power loss

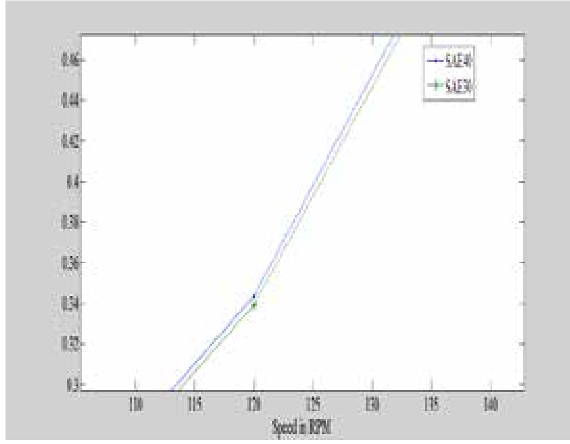

Figure 3: enlarge view of above figure

Here with the rise of speed windage power loss increases and in this graph slope of windage power loss increases with the rise of speed. In this graph the rise of density and viscosity causes increase in windage power losses. There is small effect of lubricant in the windage power loss, because in the jet lubrication maximum proportion of lubricant is air. Here with the variation of lubricant minute variation is in the windage power loss.

CONCLUSION:

The analysis of power loss data revealed that all three operating parameters density, viscosity and speed influence the spin power losses from the transmission significantly.

Specifically:

- Churning power loss significantly increases with increase in speed. Likewise, increased oil viscosity causes increased oil churning activity that results in elevated churning power loss values.
- Windage power loss significantly increases with increase in speed. Increased oil viscosity causes increased windage power loss values. With the rise of viscosity rise of windage power loss is not like as churning power loss because in the lubrication used in the jet lubrication proportion of oil and air is 1:49. So viscosity doesn't affect so much.

RECOMMENDATION FOR FUTURE WORK:

The theoretical database generated in this study exhibited clear trends in term of influence of operating parameters on transmission power loss. In order to bring a complete understanding to the measured power loss behavior, this theoretical analysis must be compared by a theoretical study.

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