

Churning Loss Estimation for Manual Transmission Gear Box Using CFD

Chandrasekhar Kodela
General Motors Technical Center India

Michael Kraetschmer
Adam Opel AG

Santosh Basa
General Motors Technical Center India

ABSTRACT

Fuel economy is one of the factors that drives the automobile sector today, and the demand for fuel efficient vehicles continues to increase by the day. Power loss in the vehicle driveline directly affects the fuel economy and must be reduced to achieve maximum fuel economy. Churning causes power loss and needs to be estimated at the design stage to arrive at the most fuel-efficient design. Using the commercial CFD tool ANSYS Fluent, as explained below, is one such way to estimate it.

Using this new method, and the steps within, permits the estimation of churning/splash losses for the complete manual transmission gear box. In the first step, CFD models are prepared to estimate the splash loss and windage loss for single gear wheel and validated against the measurement data. In the second step, a CFD model is created to estimate the splash losses for a gear pair which includes intermeshing power loss due to oil squeezing between the gear teeth, as validated by the published data. In the third step, a parametric study is done for a gear pair to find out the percentage of intermeshing losses for different operating conditions such as rotational speed, temperature and oil level. Finally, in the fourth step, a CFD method is proposed to estimate the splash losses for the complete Manual Transmission (MT) gear box.

Considering the static condition of gear box, splash loss is estimated for the gears dipped in the oil and windage power loss is estimated for the gears away from oil. To estimate the splash loss of gear pair, the individual contributions of each gear are then summed up and the percentage of intermeshing losses are added to the sum value. Splash losses for all gear pairs are added to determine the splash loss for complete gear box.

CITATION: Kodela, C., Kraetschmer, M., and Basa, S., "Churning Loss Estimation for Manual Transmission Gear Box Using CFD," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(1):2015, doi:10.4271/2015-26-0201.

INTRODUCTION

In the Manual Transmission gear box, there are two groups of power losses, load dependent losses and load independent losses. Load dependent losses occur as a result of interaction between the contacting surfaces of the gears, bearings and other parts. Load independent losses occur due to interaction of gear with the surrounding medium and the pumping of oil air mixture at the intermeshing region. These two load independent losses are collectively referred to as gear splash losses.

Viscous dissipation of bearings, synchronizer losses and sealing losses are also part of load Independent losses [1]. While losses from these two groups are often comparable under high-load, low-speed conditions, the load independent losses were shown to dominate over the load dependent power losses at higher operating speed conditions [2].

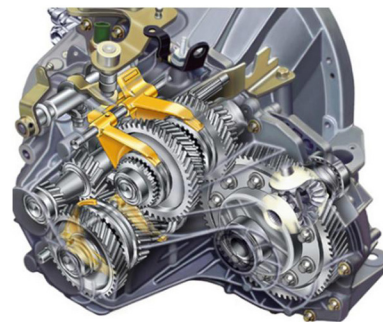


Figure 1. Manual Transmission Gear Box [7].

Manual transmission (MT) gear boxes (Figure 1) use dip lubrication in which one of the mating gears of gear pair dips below the surface of the oil at least to a depth of the order of the diameter of the gear.

Once the gear box is in the operating condition, rotational motion of dipped gear serves to distribute the oil to the mating gears and, in turn, to the entire the gear box [3].

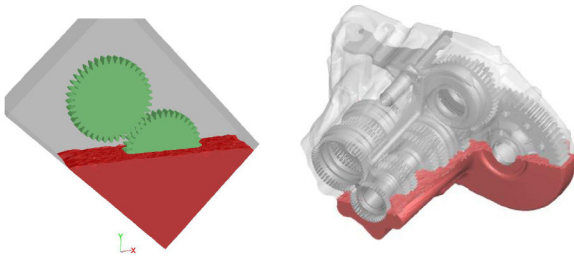


Figure 2. Dip lubrication for the gear pair and sample MT gear box, where one of the mating gear is dipped in the oil.

The lubrication throughout the MT gear box is generally ensured by splash lubrication. There is a significant amount of power loss in the form of churning or splash losses resulting from contact between the gear and the surrounding lubricant, and the squeezing of the oil-air mixture at the intermeshing region. The load independent losses play an important role (as long as the speed is high enough), especially for low load cases (like most of the fuel-economy cycles) [1, 2].

The main focus of this work is to estimate the gear splash losses in the MT gear box using CFD, which depends only on the speed of the transmission, not on its load. The estimation of gear splash losses for the complete gear box is needed to estimate the gear box efficiency and propose the alternate lubrication system in case of high churning power loss. Thus, it is desirable to obtain an estimate of the churning losses throughout the operating range of transmission at the design stage.

LITERATURE REVIEW

For load dependent losses, there are a large number of studies available, though the same is not true for the load independent power losses. There are few published studies related to load independent losses and a brief of those studies is given below [1]. There are two groups of studies related to load independent power losses, with one group focused on windage losses and the other focused on oil churning/splash losses for a single gear/gear pair.

With respect to the first group of studies, Dawson has come up with an empirical method in which to estimate the windage power loss for spur gear from a series of experiments, mostly on large gears at low to medium angular velocities [4]. Anderson and Loewenthal provided an empirical relation to calculate the windage power loss for a gear, with a pinion in mesh for specific gear applications [4]. However, the empirical formula from Anderson to calculate the windage power loss is independent of gear teeth, which can yield same windage for both disk and gear. In 2004, Diab *et al.* [4] conducted experiments to estimate the windage power loss for different size spur gears and came up with an empirical and analytical expression to calculate the windage power loss, but these experiments were done in a free environment without any enclosure.

The second group of studies, which focus on churning loss for single gear or gear pair, includes Terekhov's experiments with high viscosity lubricants and low rotational speeds for different spur gears. In doing so, Terekhov generated an analytical expression from dimensional

analysis [5]. Different analytical expressions were provided for separate flow regimes. In another study, Lauster and Boos proposed a unique expression for specific case of truck transmissions [5]. Terekhov's and Lauster's expressions derived from a number of experiments, all of which are independent of gear geometry, meaning they give the same churning loss for both gear and disk of same geometry. Boness investigated the drag torque generated by discs and gears rotating in water and oil, and derived an empirical relation for different flow regimes based on experimental observation. However, the expressions in one flow regime indicates that drag torque increases with an increasing Reynolds number, suggesting that low viscosity lubricants generate higher losses in contradiction with experimental evidence [5].

Similarly, Luke and Olver [3] performed experiments to measure the churning power loss for single gear wheel. These experiments contradicted the experimental observations when the same oil churning loss was observed to not vary significantly as temperature changes. In 2007, Changenet *et al.* [5] estimated the churning power loss for different lubricants, different speeds and different gears. The group compared the experiment-derived churning power loss and churning power loss computed using the Terekhov, Lauster and Boness formulations. None of the models gave satisfactory correlations over the parameter range of variation. Changenet *et al.* [5] derived an empirical relation to calculate the churning loss for gear wheel and for the gear pair, but the Changenet expression for churning loss of gear pair established that intermeshing losses for a gear pair with a unity ratio (1:1) is zero, which might not be the actual case.

Recently, Seetharaman *et al.* [1] conducted experiments to estimate the spin power loss for a unity ratio gear pair by varying different parameters such as the viscosity of oil, speed, oil level, and gear geometry. The group concluded that spin power loss increases with speed, oil level, oil viscosity, gear face width and gear module.

A fluid flow-based model is also derived by Seetharaman *et al.* [1] to estimate churning power loss for gear pair. This model has limitations, in that it cannot model the influence of directional rotation and makes use of static oil level instead of dynamic oil levels. Further, air ingestion cannot be taken into account at the meshing area and the difference between model and experiment is significant at high speeds.

Brief on Literature

- The literature mainly deals with experimental, empirical derived from experimental and hydrodynamic formulations (theoretical approaches) for windage and churning losses and mostly concentrated on spur gears.
- The analytical / empirical expressions available for single gear wheel did not give accurate estimates of the windage and churning losses, in that some expressions did not consider the effects of gear and/or enclosures.
- There is limited literature on gear pair for churning power loss (Changenet: Experiments and empirical model, Seetharaman: Experiments and fluid model) and both the models have significant limitations.

In conclusion, it is better to go for either measurement or virtual wind tunnel approach (CFD) to estimate the splash losses for the complete gear box. CFD is preferred and the advantages are listed in the next section.

CFD METHODOLOGY

Analytical/empirical expressions can provide the windage loss/churning loss for gear/gear pair with their own limitations and it is better to opt for the CFD method considering the following advantages.

Advantages of CFD Method

- The cost involved in CFD is lower than that involved in the experimental set up.
- The CFD can model the dynamic oil level, air ingestion at the intermeshing area and direction of rotation, whereas models (empirical/analytical) cannot.
- Models cannot take the housing effects into account, critical in that housing close to the gear has significant impact on the churning loss (Figure 3, Right).
- The additional shapes on the gear such as the differential hub on the ring gear, slots in the gear and projections on the gear cannot be accounted in the model (Figure 3, Left).
- The difficulty in estimating the intermeshing losses for the tilted gear pair conditions using model (rather intermeshing losses were neglected for tilted domain cases which is not recommended).

The following validations are required as a part of CFD method:

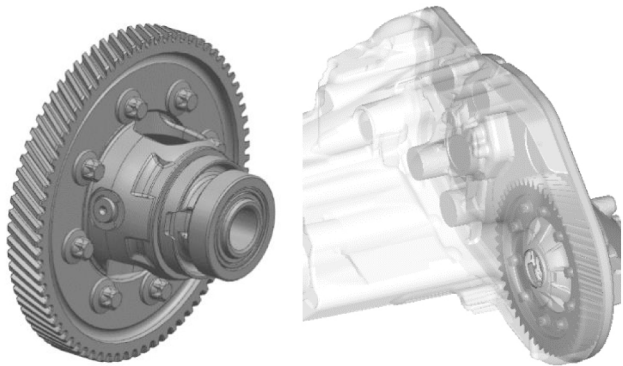


Figure 3. Ring gear with differential (Left) and different shapes on the housing (Right).

Validations Required

1. Windage power loss validation for gear wheel
2. Churning power loss validation for gear wheel
3. Churning power losses validation for the gear pair.

1. Windage Power Loss Validation for a Gear Wheel

A test case is taken from the paper [4] to validate the CFD method for the estimation of windage losses. Diab *et al.* [4] has done experiments for four gears out of which one gear is chosen for validation.

Table 1. Details of gear (Gear2 Diab *et al.* [4]) chosen for validation

Pitch Diameter	144mm
Face Width	30mm
Module	4mm
Number of Teeth	36
Outside Tip Diameter	152mm

The CFD model is created by using the steady state MRF approach in ANSYS Fluent to estimate the windage power loss for the gear wheel. The SST k- ω turbulence model is used to account for the turbulence. The measurements by Diab *et al.* [4] were done in the open air without any enclosures. To represent that in CFD the outer domain is created for gear by considering five times the radius in all the directions and the outer boundary is specified as wall, (Figure 4).

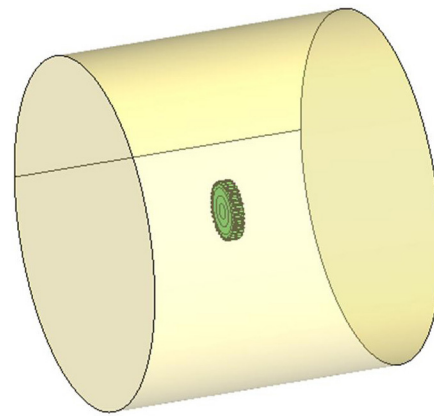


Figure 4. Gear (Gear2 Diab *et al.* [4]) and the outer domain created for CFD.

CFD simulations were performed for different speeds similar to the measurement and the windage power loss estimation using steady state MRF gives reasonably good fit with the test data with deviation of 10-15%, (Figure 5).

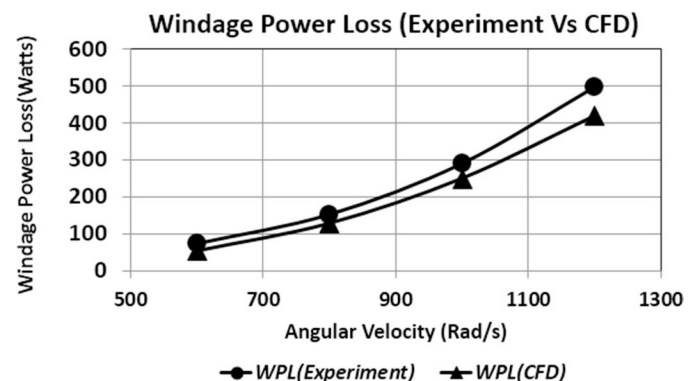


Figure 5. Windage power loss for Gear2 (Diab *et al.* [4]) Measurement vs. CFD

2. Churning Power Loss Validation for a Gear Wheel

GM did measurements to estimate the splash power losses of a ring gear with differential for a sample gear box at different speeds.