

Tribology of Prime Mover: Electric Motors

Kamal Mukherjee

The word ‘motor’ refers to any power unit that generates motion, that is a ‘prime mover’, while “electric motor” refers to a “prime mover using electricity.” Thus, the electric motor is a unit used to convert electric power or electrical energy into mechanical energy. Fig.-1. This conversion is usually obtained through the generation of a magnetic field by means of a current flowing into one or more coils. The rotation is obtained by the attractive force between two magnetic fields.

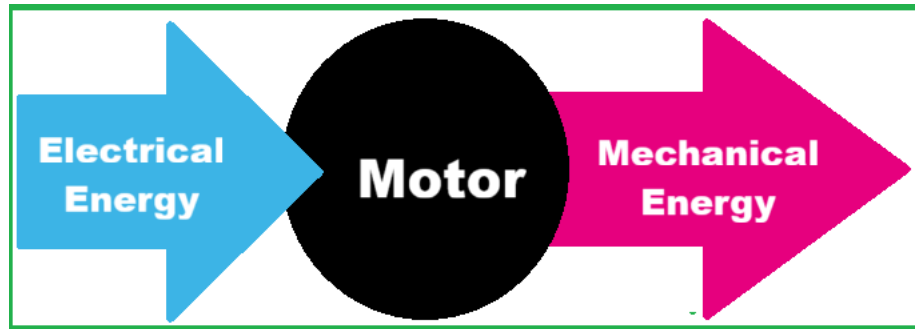


Fig-1: Input and output to and from a motor

The electric motors are very popularly used as a prime mover for driving the water pump in the house, operating the mixy in the kitchen, to run the blower to dry the hair, to dig a hole in dental teeth/skull, to drive the electric locomotive, for driving the large stationary machines e.g. winches, hoists, power gen set, etc. But of late with the introduction of electric passenger vehicles, the electric motors have created full-fledged interest, R&D, funding, study etc. at a fast pace all over the world.

Electric Motors in an Automotive Application

The drawbacks of the internal combustion engine (ICE) are relatively low thermal & low mechanical efficiencies, fuel energy being dissipated as heat, the engine exhaust contributes to particulate, nitrous oxide and hydrocarbon emissions and to the greenhouse effect via carbon dioxide emissions and the maintenance of IC engines is far more due to comparatively large number of its parts. These drawbacks have enormous influences on national and international economies. The advantage of an electric motor compared to an IC engine is that there is no soot involved in the operation thus leading to improved environmental care.

If the energy content of fuel in a car is 100% for ICEV (internal combustion engine vehicles) then only 21.5% is used to drive a petrol car according to Holmberg et al (2019). Battery electric vehicles (BEV) differ from ICEV that the combustion engine is replaced by an electric motor & electricity storing,



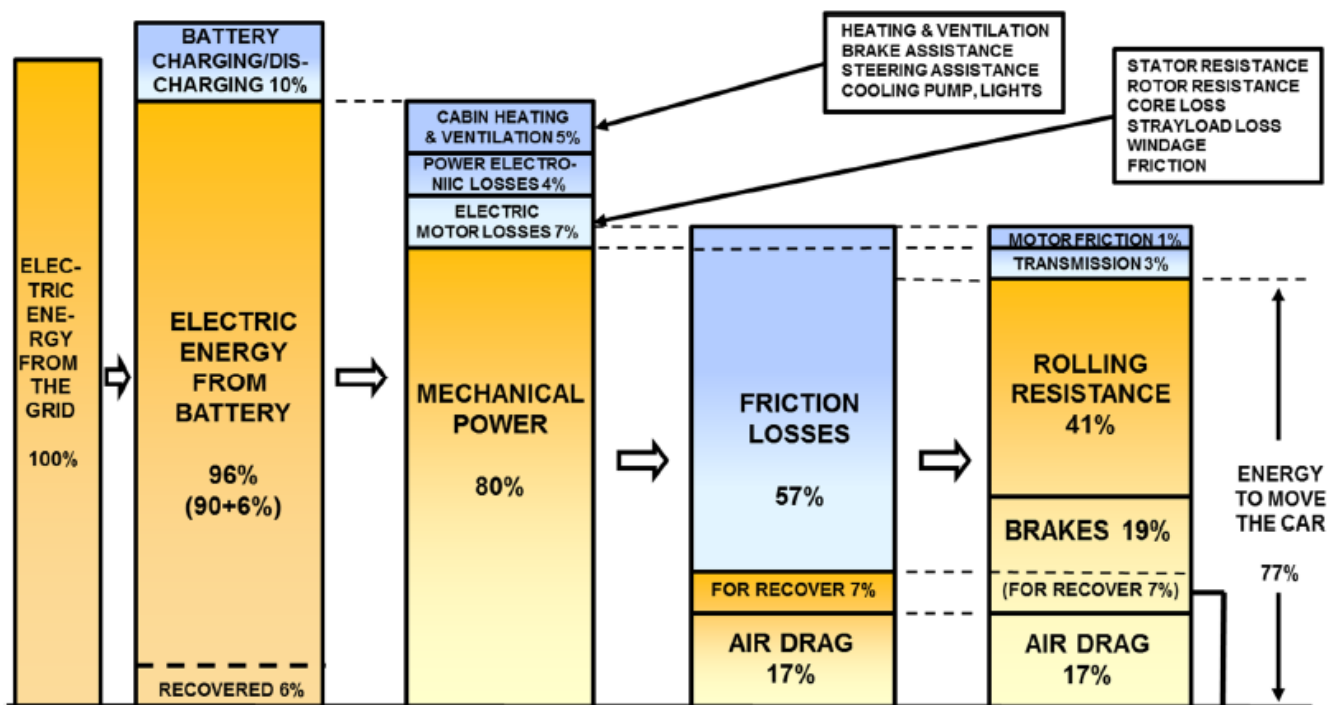


Fig-2: Distribution of energy in a typical battery driven passenger EV

charging, and control systems are added. With the same note if the total grid electric energy supplied by the battery is 100% in an EV (passenger vehicles powered by battery) then ~77% is used to drive it (Fig-2). That means the EVs are about 3.6 times more efficient than ICEVs on the basis of input energy. Moreover, the CO₂ emissions are 4.5 times higher for a combustion engine car compared to an electric car when the electricity comes from renewable energy sources.

The use of electric motors for power generation depends on the configuration in modern EVs. These include in-wheel motor (IWM) in multiple phase power systems and coreless machine (CM) in stator topology type. Similarly, in the rotor topology type synchronous brushed motor (SBM), reluctance motor (RM), synchronous permanent-magnet motor (SPM), induction motor (IM) and direct current motor (DCM) etc. The SPM provides the highest efficiency whereas DCM are the least efficient. SPM have become central to Electric Vehicle (EV) designs due to their high power-density and torque capabilities. SPMs employ an electrically excited stator and a rotor with embedded permanent magnets to create torque.

PM brushless motors are the most used motors in the automotive industry.

New AC Drive Systems

AC drives offer many advantages over traditional DC drives. Unlike DC drives, they have no brushes or commutators that require maintenance and wear out. The Insulated Gate Bipolar Transistor (IGBT) inverter technology converts the alternator power first to DC and then to variable frequency AC as used in traction motor of railway, wheel motors of large capacity dump trucks in mining etc.

Electric Motors in an Industrial Application

Induction motor

The working of an electric motor is based on the fact that a current-carrying conductor produces a magnetic field around it. The magnetic field of the magnets interferes with that produced due to electric current flowing in the conductor. Since the loop has become a magnet, one side of it will be attracted to the north pole of the magnet and the other to the south pole. This causes the

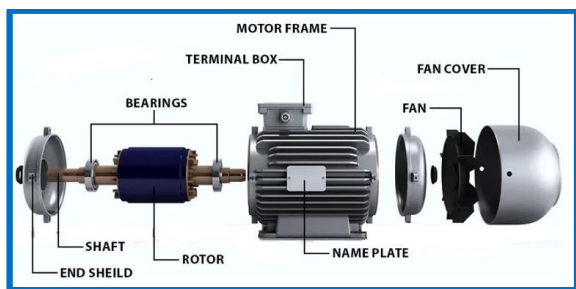


Fig-3: Schematic diagram of an AC motor

loop to rotate continuously. This is the principle of working of electric motor. Because an AC induction motor increases the flux enclosed by its stationary coils, it is a transformer with a rotating secondary (rotor). The rotor current's effect on the air gap flux causes torque. AC motors are roughly classified into commutator motors, synchronous motors, and induction motors. The rotor is housed inside the stator. The rotor is supported by the bearings at either both or one end and is covered by the side cover. A cooling fan is fitted to cool the insidious temperature as shown in Fig-3.

Servomotors

AC induction motors designed for servo operation are wound with two phases at right angles. For example, AC servomotors are used in applications requiring rapid and accurate response characteristics—so these induction motors have a small diameter for low inertia and fast starts, stops, and reversals. High resistance provides nearly linear speed-torque characteristics for accurate control. Wound-field DC motors (with copper segments in the rotor connected by magnetic-wire windings, and stator windings) are another option (Fig-4). More often, however, compact brush DC



Fig-4: A small Servo motor

motors are used as servomotors, because speed control is easy. The only variable is voltage applied to the rotating armature. Servo-built brushed DC motors also include more wire wound onto the laminations, to boost torque.

Role of Tribology for the Electrical Motors

Tribology is the multi-disciplinary subject that deals with wear and friction of the surfaces in motion. Electrical motors contain tribological components like sliding contacts (brushes), rolling contacts (ball/roller/bush bearings), damping rings, seals, washers etc. The advantage of these tribological components are they tend to fail before other components of the motor mainly because of friction and wear. So, it is the good indicator of the motor's health/performance. Thus, the tribo-diagnosis of the various tribo-components of motors determines the reliability, performance & life of the motor/generator. Some of the tribo-components are as follows:

Electrical Brushes

High-speed miniaturized motors rely on brushed and brushless technology. Typical DC motors with continuous running operation with less load and low starting current use precision metal brushes. For high torque applications, carbon brushes are preferred. Electric motor brushes are electrically conductive and work under wear conditions due to direct contact with the moving part (rotor) under the spring force in electric motors. These are used to transmit the electricity i.e. the polarity of the current flow under a constant spring pressure. It causes the faster wear of brushes so it is to be refilled frequently at a short time. This lead to improvise brushes with high conductivity. Thus, the brushes are now made with mechanical alloying (MA) by powder metallurgy. The parent materials as copper and silver are used for the electrical conductivity of the metal-matrix, graphite/graphene (C) are used as reinforcing materials, hexagonal boron nitride (hBN), molybdenum disulfide (MoS_2), and titanium diboride (TiB_2) are used to increase wear resistance and lubrication properties.

Bearings

Generally, three types of bearings are prevalent in a motor or generator. In small to medium application the ball bearings (balls have the ‘point contact’—concentrated load capacity) and roller bearings (rollers have the ‘line contact’—fairly more load capacity) are used. Whereas bush bearings (bush have the ‘arc contact’ for taking the high load capacity) are used in heavy duty applications.

Ball/Roller Bearings: The deep groove ball bearing with a focus on energy efficiency are being designed with ~30% reduction in friction losses in comparison to standard bearings. To further improve the bearing life, different advanced coating systems are used along with newly designed fluids & reducing the coefficient of friction. The coated roller bearings have resulted decrease of seven-folds in wear and improvement of ten-folds in bearing life in terms of fatigue. In coating development for reducing wear and friction, diamond-like carbon (DLC) and physical vapour deposition (PVD) coatings are quite prevalent besides some SiC ceramic matrix, etc.

A typical use in EV where the bearings wear often is the result of electric erosion and not a mechanical wear Fig.-5. The optical microscope images show the periodic wear patterns are formed by numerous microscale electrical pits.

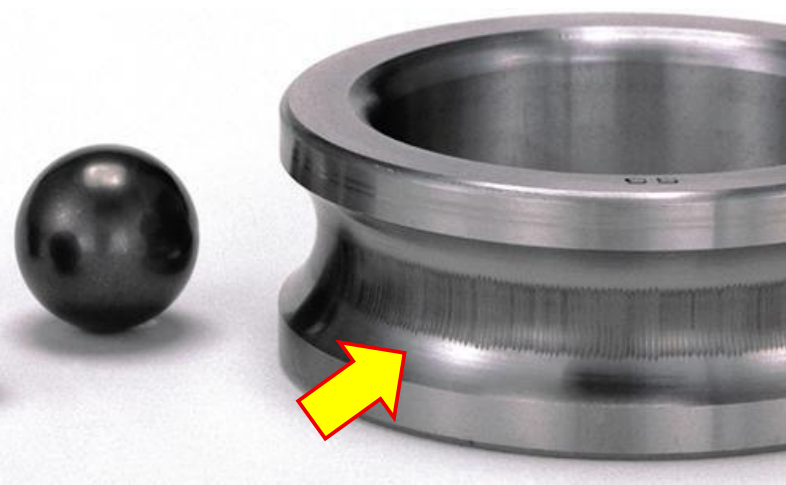


Fig.-5. Photograph of bearing inner race electrical wear

Bush Bearings: Less lubrication-based non-metallic bush bearings are the preferred choice for low speed, low load type and less service life applications. At higher speeds as well as at higher loads, the bush bearing encounters failures like wear, breakage, cold welding, etc. Sintered bush bearing is widely used option due to its low cost and suitability of wide working environment. For cost sensitive application with less service life expectancy, self-lubricated polymer-based bush bearing is the preferred option.

Lubrication

The challenges of EVs are distinct from those of electrical motors applied in traditional industrial operations. Electrically induced bearing damage (wear caused by electric discharge), and other factors are of greater concern in EVs. Electric motors are much quieter than those of ICE vehicles, drivers and passengers are more aware of any sounds and vibrations coming from the EV. Traditional Elastohydrodynamic lubrication (EHL) calculations and the electrical discharge model in bearings are completely separated phenomena. In real life the electrical discharge causes a temporary lubricant film failure, the result is brief metal-to-metal contacts that damage the bearing's raceways as well as negatively affecting the local material fatigue properties of the surface. ♦

Kamal Mukherjee, a prolific science writer and nutritionist, is an active member of the Tribological Society of India and has held executive leadership roles in major national organizations. He can be contacted at kamalcbm28@gmail.com.

