ELECTRIC MOTOR FOR PROPULSION

CASE FOR ASYNCHRONOUS CAGE ROTOR MOTOR

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With the depletion of fossil fuel there is renewed interest and it is expected there will be transition to widespread use of electric / fuel cell / hybrid vehicles. All of them have electric motor as a prime mover.

Electric Vehicles (EV) have significant potential to reduce toxic emissions such as NO_x, CO_2 emission, and noise. However once sufficient number of people drive them, emissions will be transferred from energy consumers to power plants.

EV have the potential to be entirely carbon-neutral, if CO_2 emission free energy sources like nuclear, wind and solar are used.

Fundamental drivers for e-mobility can be :

- Fast depletion of fossil fuel,
- Increasing public demand for environmental protection,
- Customer acceptance thru lower total cost of ownership and wider action radius,
- Improvement in technology, especially in storage,
- And a range of market players getting involved from vehicle manufacturers to technology providers.

Now coming on to electricity, it is one of the oldest automotive propulsion methods, still in use today. An electric vehicle was modelled by Anyos Jedlik, as early as 1828. He was the inventor of electric motor.

Electric motive power started with a small railway in 1835. This was operated by a small electric motor . This was built by Thomas Davenport and it attained a speed of 6 kilometre per hour.

Today we come across huge asynchronous cage rotor motors in traction application in Indian Railways. Typically these are multiples of 850 kW motors . Motors of size 23000 kW at 100 rpm speed propel modern cruiser ships in the world.

For that matter, asynchronous motor is one of those simple inventions which today's civilization is quite dependent on it.

1. Why an electric motor?
   That too, why an asynchronous cage rotor motor?
   - Highly reliable machine
   - Mechanically quite simple, compact in construction, few components
   - No wear outs and the parts are long lasting.
   - Easy to maintain.
   - Efficient over the complete range of speeds / operation.
   - EV 'tank-to-wheel' is quite high compared to internal combustion engines. Less impact on environment as there is no pollution while running as well as 'idle - at - rest', quiet, smooth, hence less vibration.
   - Torque can be precisely controlled with ease and hence there is comfort.
   - Can provide high torque from rest, unlike in internal combustion engines and do not need multiple gears to match power curves.
     Reduces the energy requirement in the 'start-and-stop' urban use by regenerative braking.

Electric motor is to convert electrical energy into mechanical energy. This mechanical energy provides torque to propel the vehicle.

The very same motor can be used to convert the mechanical torque to electrical energy thru regenerative braking and to give it back to the source, (eg, to charge the battery in the EV).

2. Sizing of the electric motor :

Electric motor sizing at the base speed is worked out based on the efforts needed for doing the propulsion work and also the duty cycle / usage matrix at other operating speeds.

Electric motor delivers full torque over a speed range, so that the performance is not equivalent, and it far exceeds a equivalent internal combustion engine, where as IC engine has limited torque curve.

As mentioned before the same motor will be used in the regenerative braking mode where it becomes a generator that transforms the motion into electrical power.

3. Typical Specification:

3.1 Type of electric motor

AC asynchronous cage rotor motor

3.2 Speed

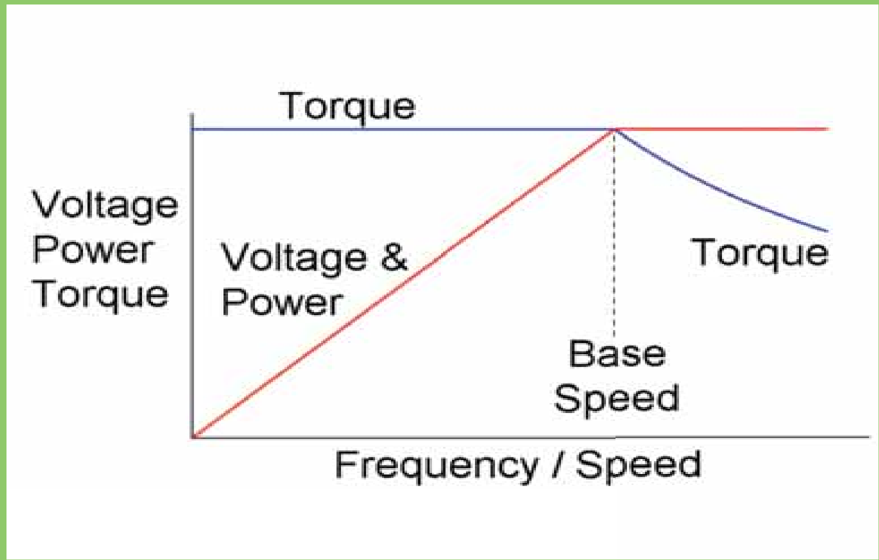
Typical design speed is 1500 rpm. However motor to be designed to operate safely over the entire speed / torque range, where top speed can go upto 10,000 rpm.

3.3 Operation mode

To operate in four modes, viz., drive forward, drive backward, regenerate while moving forward and regenerate while moving backward.

3.4 Performance – Speed / Torque requirements

Motor to deliver the required torque at the given speed from below the base speed to above the base speed. Constant torque is seen up to the base speed and variable torque is seen over the base speed. Coordinating with the adjustable speed drive, typical speed / torque imparted by the motor is shown in the picture



3.5 Efficiency

Motor to have high efficiency over the sustainable speed range.

3.6 Reliability targets against vibration, mechanical shocks, thermal / power cycle and shock thermals are - 10 years of life covering 1,50,000 km and 5500 hrs of operation.

3.7 Underhood environment

3.7.1 Ambient – 20^o to 50^o C

Temp. Class 180^o C

3.7.2 Thermal requirements

To take care of the thermal power cycle as well as thermal shocks.

3.7.3 Enclosure : To protect against ingress of contamination, water.

3.7.4 Weight : High kW/weight ratio - means as light as possible to be worked out with the car manufacturer.

3.7.5 Overall dimensions :

Overall length and diameter of the motor will be restrictive to be worked out with the car manufacturer.

Motor cooling – external cooling.

3.7.6 Motor cooling – external cooling.

3.8 Noise and vibration :

- Noise 60 dB (A) at 8000 rpm
- Vibration 0.5 mm/s throughout the entire speed range.

3.9 Corrosion :

Motor winding parts, hardware to withstand corrosion throughout its intended life.

3.10 Humidity :

Motor to be tropicalized for humid conditions.

3.11 Mechanical requirements :

Rigid enough to take care of the vibration, random mechanical shocks.

3.12 Electro Magnetic Compatibility (EMC) :

Radiated and conducted emissions shall not interfere with any other vehicle or charging function nor shall the motor operation be degraded by emissions.

3.13 Safety against hazards like

- Uncontrolled heating
- Electrical fault
- Protection against access

3.14 Bearings for life to be provided.

3.15 Sensors for speed and temperature monitoring.

4. DESIGN CRITERIA:

Summing up the customer requirements from the above typical specification, one will observe that the electrical motor to provide widespread torque characteristics, high ‘power-to-weight’ ratio, high efficiency, high overload capability, minimum maintenance and of course low cost.

As mentioned before ac asynchronous cage rotor motors have these best features. However they have to be specifically designed to meet all these requirements.

4.1 Selection of motor speed :

Motor with speed of 1500 rpm or 4 poles can give the best performance for entire speed range, in the present context.

4.2 Lamination :

For this special purpose motor emphasis will be on very high break-down torque (maximum torque) and also high efficiency throughout the operational range. We need to balance out the resistance and the reactance values of the machine for these high performance requirements. Slot combination as well as the optimization of the slot design is very important for the performance of the motor in both the constant torque and constant power regions of operation. Further right choice of grade and thickness of the lamination steel sheet is detrimental to high efficiency of the motor.

Sheet thickness can be as low as 0.35 mm. Due care is taken in the design of magnetic circuit using these low loss laminations to avoid the magnetic saturation in the constant torque region. Further using a lamination with higher permiability means a lower magnetic resistance for the magnetic flux and hence lower magnetizing current. That leads to an one hand to higher torque in the base speed range and on the other hand a lower torque in the field weakening range because of lesser magnetic resistance for the leakage flux, which leads to higher leakage inductance.

4.3 Winding :

There is no special winding design or layout in the stator. One has to be careful in the layout, such that there is least possibility of circulating currents due to unbalance and harmonics. These harmonics can be due to the imbalance in the electromagnetic structure in the motor as well as from the operation of the controller.

Coming on to the rotor winding, it can be of diecast aluminium alloy or copper.

Rotor with copper winding will marginally increase the efficiency at a cost.

4.4 Insulation :

With limitation on the size of the motor inside the car, in mind, a smaller motor will operate at higher operating temperature during steady running as well as pulsating thermal cycles.

This motor will have 180 temperature class (Class H) insulation system. Magnet wires will have dual coat class H, inverter duty enamel covering. Winding is globally trickle impregnated with class H resin.

These magnet wires and the winding insulation system have to be reliable as they have to meet the thermal-power matrix, and the thermal shocks.

Additional care also need to be taken due to high voltage, repetitive spikes and additional heating due to harmonics. Special scheme of insulation for adjustable speed drives, approved by Underwriters Laboratory, USA, is implemented. This scheme has the capability to withstand corona inception voltage (CIV) of 2.1 kV with steep surge for satisfactory operation.

4.5 Bearings :

These motors will have suitable anti friction rolling bearings with high temperature class lubricant ‘sealed for life.’

4.6 Housings :

To reduce the weight of the motor all mechanical components like motor housing, its brackets will be of aluminum alloy.

5. Process :

Apart from the design consideration, best practices in processes have a very large impact on sensitive issues like vibration, noise and temperature of the motor.

Lamination with controlled burr and proper stacking will bring about reducing in core heat, and magnetic noise. Proper winding layout will contribute to reduction of unbalanced magnetic pull, harmonics and heat. Good control on mechanical dimensions of mating components, and the air gap will result in the reduction in magnetic pull, noise, vibration and heat.

Windings and cables handle high amount of current in part of a cycle. Hence winding and cable conductor sizes quite large and have to be properly terminated from point of reliability.

6. Acknowledgement :

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