Replacing an engine with an electric motor? Horsepower is horsepower – or is it?

By Chuck Yung
EASA Senior Technical Support Specialist

Editor's Note: PDFs of this article are available in English and Spanish in the "Resource Library" of **www.easa.com**.

• • • • •

When a customer calls and wants to replace his diesel or gasoline engine with an electric motor to drive a piece of machinery, it's easy to assume that "horsepower is horsepower." Not so fast! It turns out that there are many different ways to measure power. The term horsepower was adopted by James Watt in the late 1700s to compare the output of steam engines to draft horses. Aside from North America, most of the world uses the International System of Units (SI) unit *watt* to describe power output. Since the 1700s, we have mechanical hp, kW, metric hp, electric hp, hydraulic hp, drawbar hp, brake hp, shaft hp and even variants of taxable hp. Leave it to governments to want a piece of the action.

> *"Our concern is when a customer has a gas engine, diesel engine or some other power source, and wants to replace the prime mover with an electric motor. The goal is to do work, so the customer assumes he/she needs the same hp. The reality is we need to review the relationship of torque, work, rpm and power."*

The purpose of this article is to increase awareness about the many factors which must be considered when making such a seemingly simple substitution.

The historical perspective makes for fascinating reading. Mechanical hp, or imperial hp, is approximately 745.7 watts, and was originally defined as 550 pound-feet (746 Newton-meters) per second. Watt derived his formula for hp based on how many times a horse could turn a wheel of known size and weight. The particulars are not important to this discussion, so I will leave it there. His formula was quickly rounded to 33,000 pound-feet (44 741 Newton-meters) per minute.

Most readers realize that it is **torque x rotation** that produces work, and the following formula for power should be familiar:

hp = (T × N)/ 5252 or

kW = (T × N)/ 9550

T = torque measured in pound-feet or Newton-meters

N = rpm

Or, in SI units, P = t x ω where t represents torque and w equal watts

For our purposes: Mechanical horsepower = 746 watts

Metric hp = 735.5 watts

Electric hp = 746 watts

Hydraulic hp is derived from flow rate (gpm) × pressure (inches of water column) × 7/12,000 but conveniently works out to 745.7 watts.

And finally, air hp works out identically to hydraulic hp.

Our concern is when a customer has a gas engine, diesel engine or some other power source, and wants to replace the prime mover with an electric motor. The goal is to do work, so the customer assumes he/she needs the same hp. The reality is we need to review the relationship of torque, work, rpm and power.

Torque is the twisting force, such as when we tighten or loosen a bolt. A torque wrench displays how much force (in pound feet) is applied. Power is the measurement of work and speed, for example 100 pound-feet (135.6 Newton-meters) of torque times the rpm to perform work. One horsepower equals 550 pound-feet (746 Newton-meters) per second.

Loading bricks on a three-foot high platform is a good example to illustrate torque, horsepower, and work. Lifting twenty bricks, each weighing 10 pounds (4.54 kg), per minute:

3 ft. (1 m) × 10 lbs (4.54 kg) × 20 bricks = 600 pound-feet (813.5 Newton-meters) of work. Since we need to consider the time it took to determine how much power was used, 600 pound-feet (813.5 Newton-meters) / 60 seconds equals 10 ft-lbs (13.56 Newton-meters) per second of power.

Since 1 hp = 550 ft-lbs (746 Newton-meters) / second, we used 0.0182 hp (10/550 = 0.01818) or (13.56 Newton-meters).

If another person loads the same number of bricks in only 20 seconds, he used three times as much power, or 0.0546 hp to do the job faster. So the rpm is an important variable when replacing an engine with an electric motor.

Must know speed

Here is why it is important to know not only what the driven machinery is, but also the speed at which it is driven.

According to one source:

"The gross power rating for individual gas engine models is labeled in accordance with SAE (Society of Automotive Engineers) code J1940 (Small Engine Power & Torque Rating Procedure), and rating performance has been obtained and corrected in accordance with SAE J1995 (Revision 2002-05). Torque values are derived at

Continued on Page 2

Replacing an engine with an electric motor? Horsepower is horsepower – or is it?

Continued From Page 1

3060 rpm; horsepower values are derived at 3600 rpm."

The horsepower rating for a gasoline engine, then, is rated for a specific speed – 3600 rpm. Confounding us further, a gas engine loses torque as it slows down – it can be stalled. A diesel engine is rated for horsepower over its wider speed range, so a 100 hp (75 kW) gas engine is not equivalent to a 100 hp (75 kW) diesel engine. And an electric motor, we know, produces torque because of slip – the marginal difference between synchronous speed and actual speed, and that torque increases as load increases from no load up to stall. So while the slip falls within a narrow range, the electric motor produces more torque as it slows down – at least, until it overheats and fails.

Compared to gasoline:

"Torque values are derived at 3060 rpm; horsepower values are derived at 3600 rpm."

A gasoline engine has a peak torque value for a given rpm (3600). It's easy to interpret that as a hp rating – measured torque at a specific rpm. An electric motor produces torque in response to load. As the load is increased, the rpm decreases and the current increases, so the electric motor produces more torque. **The actual rpm at which torque / hp is measured varies with the engine size.** For a direct comparison between gasoline and diesel

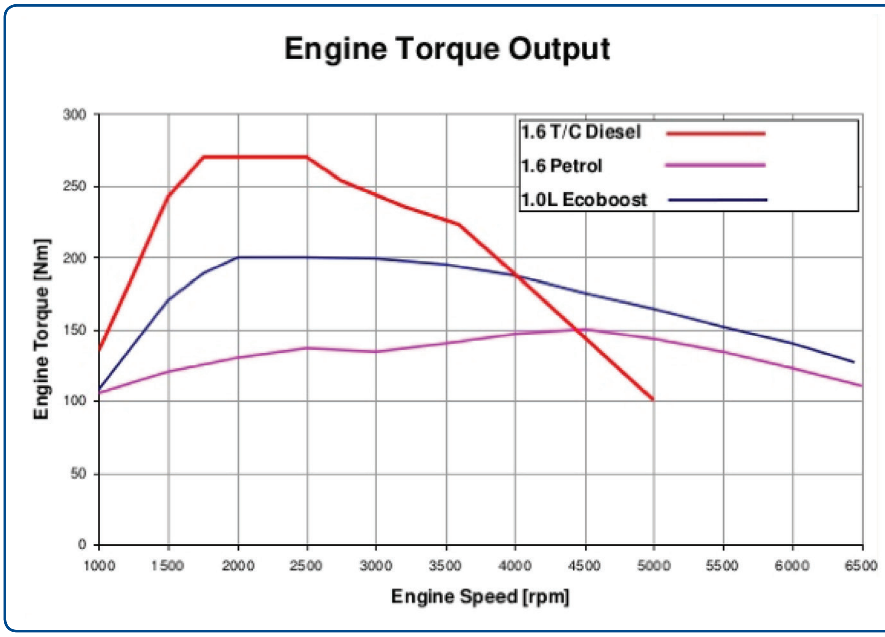

Figure 1. Torque comparison for diesel versus gasoline engines.

engines, consider the speed torque curve in **Figure 1**, which compares conventional diesel, gasoline (petrol) and the European Eco-boost diesel engines. Notice that, for the same displacement, the conventional diesel engine develops over 140% as much torque at 1800 rpm as the gasoline engine.

It is convenient and logical to define electric motor hp (or kW) based on the speed and torque it can produce.

Brake hp is the power as measured at the crankshaft of an engine. Shaft hp is the power delivered to a shaft, be it a propeller shaft, turbine shaft, or even the output shaft of a gearbox or transmission. For engines, Brake hp is used, because shaft hp would require consideration of losses in things like transmissions.

Without going too far off topic, SAE standards for measuring hp of engines have changed several times over the past 60 years, so hp ratings of gas engines might have changed even though there was no change to the engine design.

So, a gas engine is rated in hp at 3600 rpm but the torque is determined at 3060 rpm; a diesel engine provides full torque throughout the speed range; and an electric motor is rated at specific hp at specific (synchronous) speeds.

Other considerations

Now we consider the type of load, and how that affects our replacement options. Many of our customers' applications involve pumps, fans or blowers, most of which fall under the heading of variable torque loads. A unique aspect of the affinity laws that govern most of these applications is that **there is a cubed relationship between the speed we drive them, and the hp required to do so.**

So a gasoline engine driving a pump at 1950 rpm might be a 100 hp (75 kW) engine, but that 100 hp (75 kW) rating was derived at 3600 rpm. Here's what happens if we assume "horsepower is horsepower" and supply a 100 hp (75 kW), 4-pole electric motor:

The torque curve of a gasoline engine varies in non-linear fashion, so this example is not applicable to all gasoline engine ratings.

"Brake hp is the power as measured at the crankshaft of an engine. Shaft hp is the power delivered to a shaft, be it a propeller shaft, turbine shaft, or even the output shaft of a gearbox or transmission. For engines, Brake hp is used, because shaft hp would require consideration of losses in things like transmissions."

Continued on Page 3

Replacing an engine with an electric motor? Horsepower is horsepower – or is it?

Continued From Page 2

1950 / 3600 = 0.54 so that "100 hp (75 kW) gas engine" *might have only been producing about 54 hp (40 kW) driving the pump at 1950 rpm.* The 1950 rpm is 5 ½% faster than the synchronous speed of a 4-pole 60 Hz electric motor, so we need approximately 27% more hp to drive it at 1950 rpm (assuming a variable frequency drive [VFD] is used) than we would need at 1800 rpm.

$$1950 / 1800 \wedge 3 = 1.27$$
$$1.27 \times 54 = 68 \text{ hp } (51 \text{ kW})$$

With a VFD driving the pump at the original 1950 rpm, we need 127 hp (95 kW). If we sold the customer a 100 hp (75 kW) because "hp is hp," we sold him a motor that is nearly 1 ½ times the size required.

What if he said: "No, I don't want a VFD. I'm happy just driving the pump at 1800 rpm"? According to our affinity laws, they only need a 50 hp (37 kW) motor:

$$(1800 / 1950) \wedge 3 \times 54 \text{ hp } (40 \text{ kW})$$
$$= 43 \text{ hp } (32 \text{ kW})$$

If we sold the customer a 100 hp (75 kW), we've really oversold them. The cost of the motor, the switchgear and – adding insult to injury – the power factor of the oversized motor could even cost them penalties on their power bill.

For constant torque loads, or constant power loads, we must further consider the type of application. A summary of the unique starting characteristics based on the NEMA design letter (and IEC equivalents) is shown in **Table 1**.

Table 1. Summary of the unique starting characteristics based on the NEMA design letter (and IEC equivalents).

	NEMA B	NEMA C	NEMA D	IEC H	IEC N
Locked rotor torque	70-275%	200-285%	275%	200-285%	75-190%
Breakdown torque	175-300%	190-225%	275%	190-200%	160-200%
Locked rotor current	600-800%	600-800%	600-800%	800-1000%	800-1000%
Slip	0.5% - 5%	1-5%	>= 5%	1-5%	0.5% - 3%
Applications	*	**	***	**	*
*Fans, pumps, blowers, compressors, MG sets					
**Conveyors, crushers, agitators, reciprocating pumps or compressors					
***High peak loads, w/wo flywheels, including punch press, shears, elevators, winches, hoists, or pump jacks					

What's the answer?

When a customer calls with the request to replace his gas / diesel engine with an electric motor, find out what the application is and gather as much nameplate information as possible from the driven equipment. Then call the manufacturer of the driven equipment and ask what size electric motor they recommend. In nearly all cases, the OEM already supplies this same piece of equipment with an electric motor, so they know what size motor is required.

If the OEM is no longer in business, consider the application, as well as the ratio of original speed to electric motor synchronous speed. Determine the torque requirement and ask your customer to verify the actual hp the load is asking of the engine. A grossly oversized electric motor will have higher initial and operating costs.

Does the application call for a design C or D? If so, no amount of oversizing will make a design B perform satisfactorily. If the load is variable torque, factor in the affinity laws to determine the actual required hp. ●