



Torque Density and Hydraulic Motors

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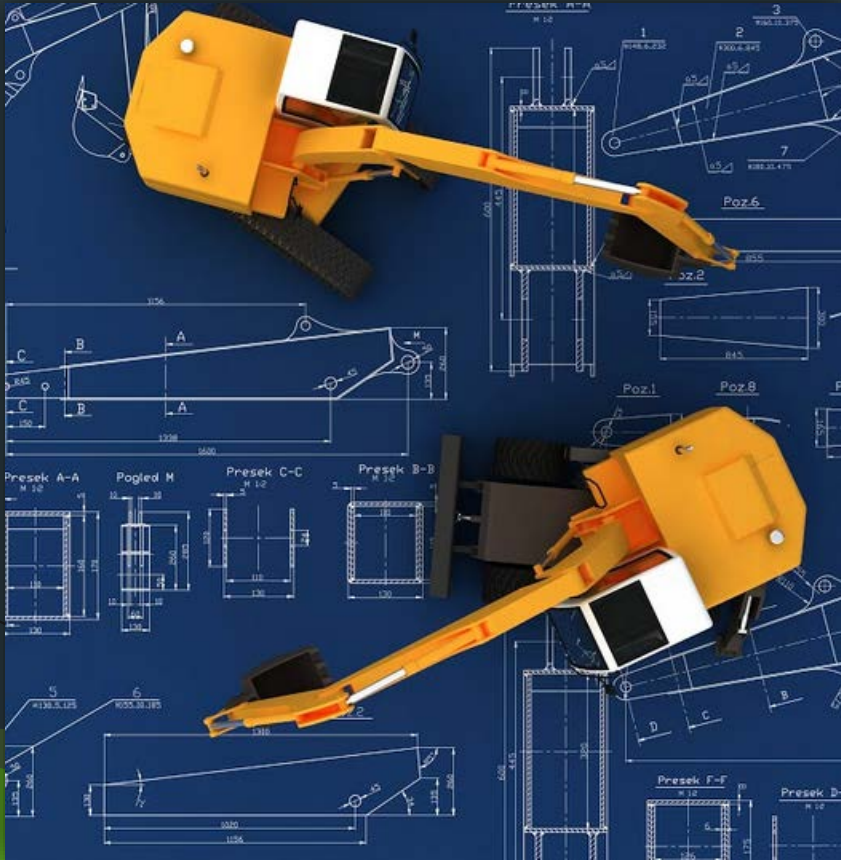
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Torque Density and Engineering Design



Torque Density: an overlooked but vital parameter in machine design

In pursuit of improved design and performance of mechanical systems, *designers, manufacturers, and end users* must consider numerous parameters and scenarios.

Factors such as

- power requirements
- Available space
- operation and maintenance
- installation constraints
- potential failure modes
- budget limitations

often play key roles, along with a variety of application-specific factors unique to each system.



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Overlooked Parameter

One often overlooked parameter is torque density.

While not as commonly considered as other measurements such as *power, work, and lifting capacity*, torque density can help designers make smarter decisions by focusing on "*where the work gets done.*"

Torque density can be applied in a variety of industrial and mobile applications, and *can provide both immediate and long-term benefits*. Let's take a look at how this works.



Fundamentals of Power and Torque



Before exploring torque density, a brief review of *power* and *torque* can help set the stage for the importance of torque density as a design parameter.

Reviewing Power

Power is often defined as the *rate of doing work*.
In physics terms, this is expressed as:

$$P = W/t$$

where P = power, W = work, and t = time.

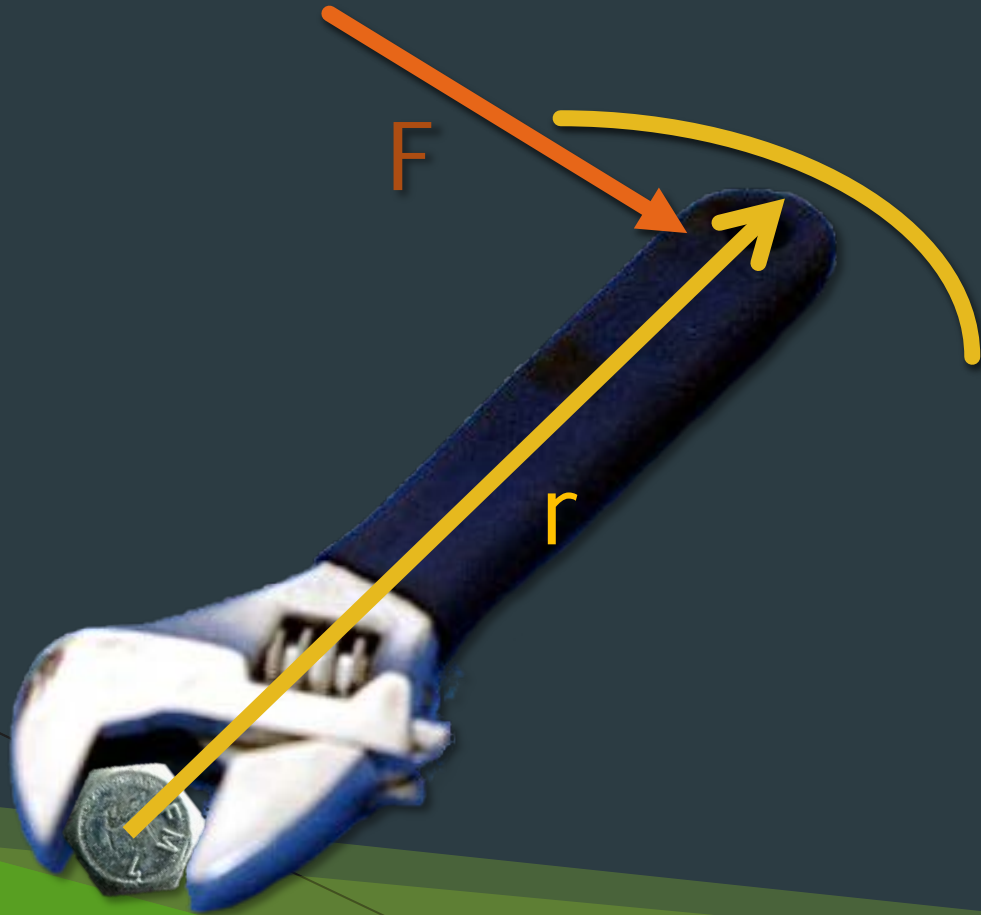
The metric (SI) unit of measurement for power is the Watt, also expressed as Joules per second.

The English (Imperial) unit is the horsepower.

For the purpose of rating motors, one horsepower equals approximately 746 Watts.



Reviewing Torque



Torque is a measure of the turning force on an object being rotated, such as a bolt or an automotive flywheel. Again returning to basic physics:

$$T = F \cdot r$$

where T = torque, F = the force applied, and r = the radius of the arc along which the force is applied.

Torque is usually expressed in units of Newton-meters or foot-pounds.

Relationship between Torque and Power

Torque can also be expressed in *terms of power*. Through a mathematical conversion that will be omitted here for brevity, one can state power as follows:

$$P = T \cdot \omega$$

where P = power, T = torque, and ω = angular speed in revolutions per minute. Rearranging terms, power in horsepower can be expressed as follows:

$$HP = (T \cdot \omega) / 5252$$



Torque and Hydraulic Motors



This becomes important when designing machine systems with motors and gear boxes. Torque from a motor at the input end of a gear box can be converted to a lower rotational speed and transmitted to the output end to drive a machine.

In a motor vehicle, the transmission adapts the output of the engine to the drive wheels, reducing the engine speed to an appropriate wheel speed, increasing torque in the process to accomplish work (i.e., *propel the vehicle*).

Power Density

To evaluate how much power can be generated in a given space, system designers sometimes use the term **power density**.

This is typically expressed as the amount of power per unit volume, such as Watts per cubic meter (W/m^3).



Concept of Torque Density



Torque density is a similar concept, except instead of quantifying power, it expresses the ratio of torque capability to volume, in units of Joules per cubic meter or foot-pounds per cubic foot.

In short, it measures the torque-carrying capability of a component in a given weight and space envelope.

Importance of Torque Density

*In the design of mechanical systems, torque density can be used to make **smarter design decisions**.*

Using consumer product analogies, purchase choices are often incorrectly made based on "*brute force*" factors such as how many Watts an amplifier puts out, or the horsepower rating of an engine in a pressure washer.

More in-depth considerations review how efficiently an amplifier delivers a signal to its speakers, or how much water flow the pressure washer delivers at a certain pressure.



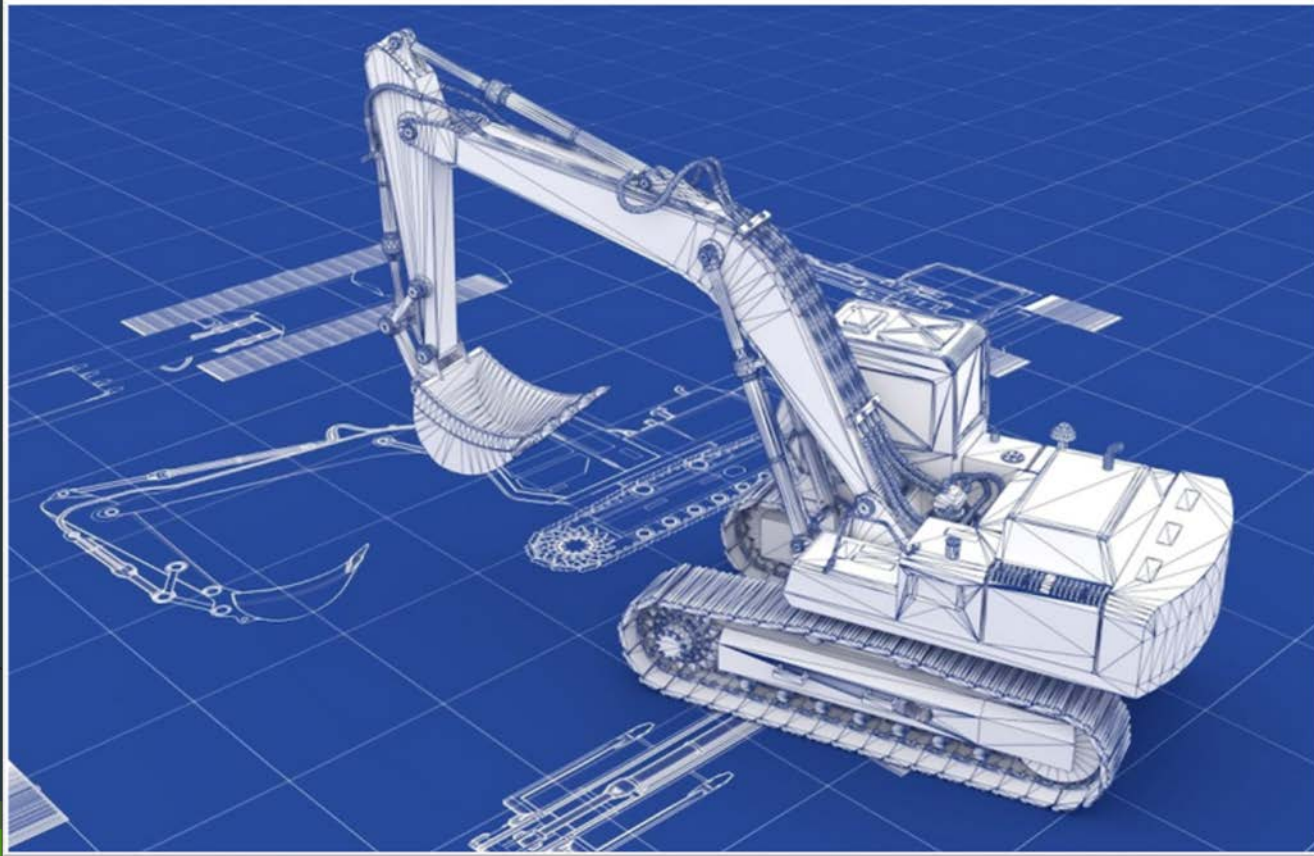
Limitations of Power Ratings

Power ratings alone can indicate the available capacity of a mechanical system, but do *not always provide the best overall measure of system performance.*

Torque density measures how much rotational force is applied in a given space, essentially measuring performance "*where the work gets done*" instead of simply measuring how much power is available.



Concept Evaluation



When considered during the *concept evaluation stage* of mechanical designs, torque density can be used to evaluate the potential success of various concepts. Multiple design solutions might be available, but when space is limited, the relative torque densities of the solution may help determine which design provides the *most efficient footprint*.

Industrial Example: Mining Equipment

As an example, consider an *industrial gear box* used for mining equipment.

If the gear box size is based on the power requirements in an electro-mechanical system, with the electric motor mounted near the gear box, large counterweights would be required to provide balance to the machine.



Industrial Example: Mining Equipment

Based on *torque requirements* and a *hydraulic solution*, the power unit can be located where it is most convenient.

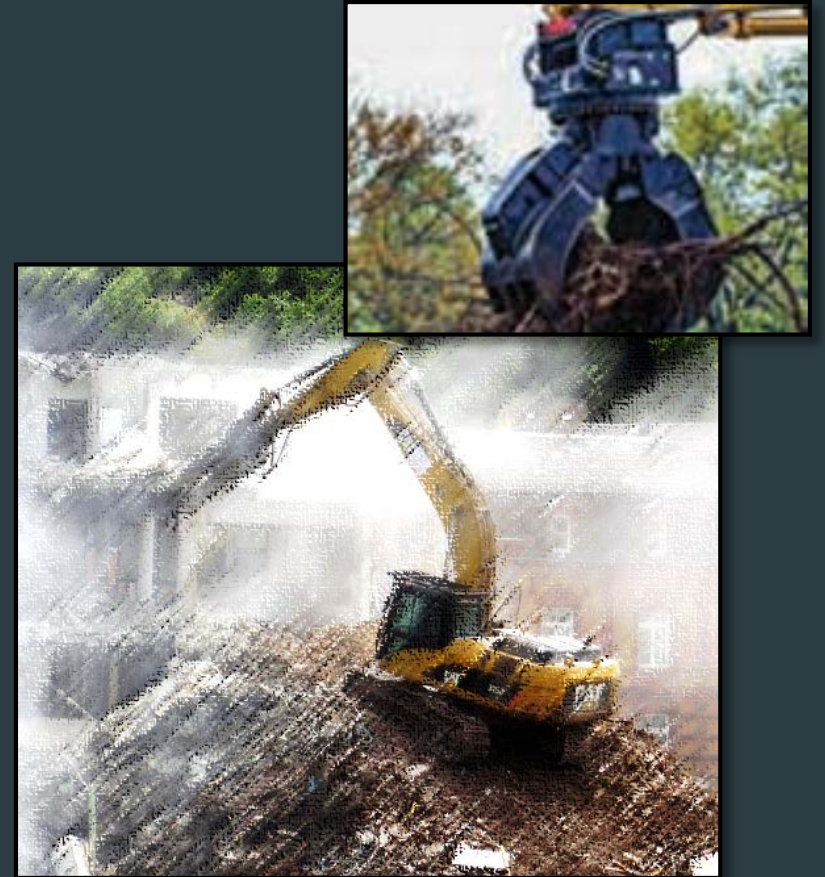
The actuator can then make use of superior torque density, lowering the requirements for additional counterweights and *saving substantial machine structural weight and cost*.



Mobile Example: Rotating Grapple

As another example, consider an excavator with a **rotating grapple**. The grapple makes use of a motor-driven worm gear that delivers a high amount of torque in a relatively small space.

If the excavator design was based primarily on power or speed considerations, a direct drive mechanism would likely be used, requiring additional space. The smarter design, balancing power, torque, and rotational speed, enables innovations such as the *rotating excavator* to become feasible.



Paybacks From Using Torque Density for Product Design and Selection

The need to deliver torque is often a complex challenge. A traditional approach based on power or rotational speed might lead to unnecessarily bulky solutions. By using **torque density** as a **key parameter**, numerous paybacks can be achieved, such as:

- **More efficient operations** through space savings
- **Cost savings** due to optimal component selection
- **Innovative designs** and new products
- **Extended equipment life due** to better matched components
- **Noise reduction** due to smaller motors



Conclusion

▄▄ *With torque density at the forefront, designers, manufacturers, and end users can all benefit from **smarter machine designs.***



Authors



Lyle G. Meyer
Product Manager,
Industrial Drives



Todd D. Degler
Product Manager,
Geroler® Motors



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Who do I contact for more information?

For Business and Customer Support

EMAIL: sales@TexasFinalDrive.com

PHONE: 1-888-934-6257

WEBSITE: TexasFinalDrive.com



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