Calculating Dynamic Loads, Sizing Worm Gears and Figuring Geometry Factors

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Answers submitted by Robert Errichello, Gear Consultant, GEARTECH, Townsend, MT, and Technical Editor, Gear Technology

Questions submitted by Mark H. Swalley, U.S. Navy, Puget Sound Naval Shipyard, Bremerton, WA

Q: What is the best method to measure or calculate dynamic loads in a low-speed spur gear subject to load reversals?

A crane's gear train is subject to sudden load reversal when an emergency brake suddenly applies on the hoist drum. As the drum comes to a sudden stop, thanks to large caliper brakes, the electric-powered drive train continues to rotate. The backlash is taken up, and the pinion gear contacts the opposite face of the drum's bull gear. The pinion gear is on the output shaft of the speed reducer. The impact is so violent, the pinion gear stand bolts snap the head off, ricocheting around the machinery house.

The gear train has about 10 times the inertia of the hoist drum. To complicate matters, the electric motor has time to produce regenerative braking prior to impact.

A: Strain gages are commonly used to measure dynamic loads. They are a good choice because they are readily available, relatively inexpensive, and accurate for capturing transient loads such as you describe. Computer modeling, on the other hand, is accurate only if mass, stiffness and damping are precisely known. Damping is especially difficult to estimate and usually requires strain measurement on the actual system to determine accurate values. Therefore, strain measurement is the best choice for determining dynamic loads in your application. Additionally, the measurements can help determine system damping, which you could use in a computer model to explore alternative design changes to reduce dynamic loads.

Q: How should the strain gages be placed, and how should the signal be transmitted?

I am currently working out a full Wheatstone bridge arrangement. Strain gages will be placed on the ends of the 19 gear teeth, one on either side of the gear tooth base (the high tension/compression areas). The 38 gages and two dead gages will be divided into four legs of 10 gages in series. The signal will be transmitted from the rotating shaft via one of the telemetry-type strain transmitters.

That arrangement will reduce the signal about five times over the single gage in a $^1/_4$ bridge circuit, but will transmit a constant signal. The transmitter sends 500 signals a second, and I believe that to be fast enough to catch the dynamic event. I can correlate the results to strain gages reading from a steady state load.

A: Your transducer and method of transmitting signals are state-of-the-art. To capture tooth bending stresses, the gages should be placed on the root fillet at the point of maximum bending stress. That point can be found by painting the root fillets with brittle lacquer and applying loads to the gears. The first place to crack the brittle lacquer is the point of maximum stress. However, it is seldom practical to mount gages at the critical point because of interference with the mating gear's tips. You need to decide what it is you want. Is it maximum tooth bending stress, or is it the maximum dynamic torque applied to the gears? It may be sufficient to measure the torque and calculate tooth stresses.

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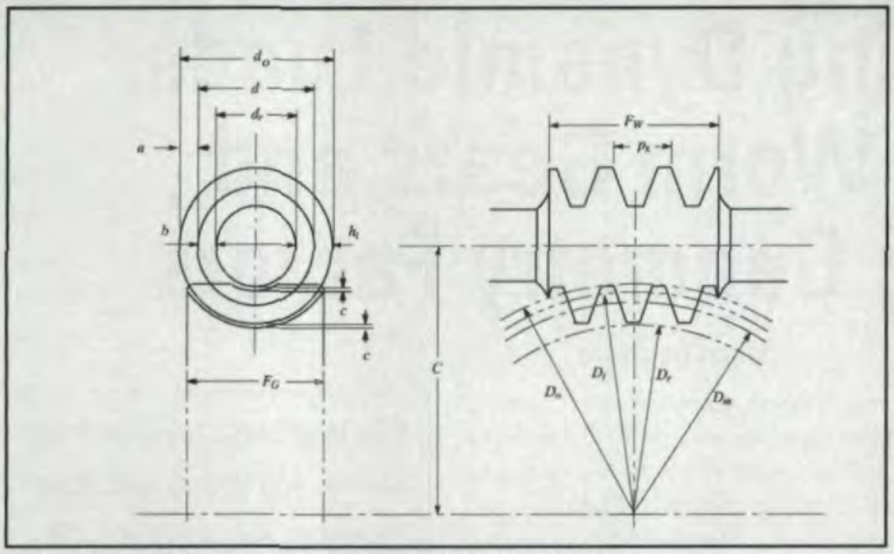

Fig. 1 — Worm gear basic dimensions. Source: ANSI/AGMA 6022-C93.

Table 1—Definition of symbols.

a	Worm and worm gear addendum
b	Worm and worm gear dedendum
C	Center distance
c	Clearance
D_m	Worm gear mean diameter
D_o	Worm gear outside diameter
D_r	Worm gear root diameter
D_t	Worm gear throat diameter
d	Worm pitch diameter
d_o	Worm outside diameter
d_r	Worm root diameter
F_G	Worm gear face width
F_W	Worm face width (Thread length of worm)
h_t	Full depth of worm thread
p_x	Worm axial pitch

Source: ANSI/AGMA 6022-C93.

Question submitted by Christian Williams, Texas A&M University, College Station, TX

Q: How does the desired gear ratio for a worm and worm gear relate to the actual size of the gears? For example, if I want a gear ratio of 30:1, what diameter constraints are placed on the gears for that ratio?

A: Worm wheel diameter is set by required load capacity. ANSI/AGMA 6034-B92, "Practice for Enclosed Cylindrical Wormgear Speed Reducers and Gearmotors," relates worm wheel diameter to tangential load as follows:

$$Dm = [Wt/(Cs\ Cm\ Cv\ Fe)]^{1.25}$$

Where:

- Dm = mean diameter of the worm wheel
- Cs = materials factor (accounts for the worm wheel material's strength)
- Cm = ratio correction factor (accounts for the gear ratio)
- Cv = velocity factor (accounts for sliding velocity and varies with diameter, lead and speed of the worm)
- Fe = effective face width of the worm wheel ($Fe = F_G$ or $Fe = (2/3)d$, whichever is less.)
- Wt = tangential load

The diameter of the worm can vary somewhat without significantly influencing load capacity. ANSI/AGMA 6022-C93, "Design Manual for Cylindrical Wormgearing," recommends a worm diameter in the following range:

$$\frac{C^{0.875}}{3.0} \leq d \leq \frac{C^{0.875}}{1.6}$$

Where:

C = center distance
d = worm pitch diameter

ANSI/AGMA 6022-C93 provides guidelines that give a practical overview of worm gear design.

You should audit the gearset to ensure it meets the design guidelines of ANSI/AGMA 6022-C93 and rate the load capacity in accordance with ANSI/AGMA 6034-B92 to ensure it has an adequate service factor for the application.

Question submitted by Richard Friedman, Nichols Aircraft Division, Parker Hannifin Corp., Ayer, MA

Q: Is there a closed-form solution for the Lewis form factor?

A: No, there is no known closed-form solution. However, an efficient algorithm for numerically solving the problem is given in AGMA 908-B89 (Ref. 1). The algorithm is readily programmed using the flow chart given in AGMA 918-A93 (Ref. 2). Benchmark examples useful for validating software are given in Reference 2 and tables of J factors are given in Reference 1. The algorithm derives from References 3 and 4.

References

1. AGMA 908-B89, "Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth," April 1989.
2. AGMA 918-A93, "A Summary of Numerical Examples Demonstrating the Procedures for Calculating Geometry Factors for Spur and Helical Gears," Jan. 1993.
3. Errichello, R. "An Efficient Algorithm for Obtaining the Gear Strength Geometry Factor on a Programmable Calculator," AGMA Paper No. P 139.03, Oct. 1981.
4. Errichello, R. "An Efficient Algorithm for Obtaining the Gear Strength Geometry Factor for Shaper Cut Gears," AGMA Paper No. P 139.05, Oct. 1983.