A Conversation With Darle Dudley

Gear Technology *consults with a master gear engineer.*

Nancy Bartels

For many years, when gear engineers have been confronted with tough problems either in the field or on the drawing board, one of the inevitable suggestions has been, "Ask Darle Dudley," or "Check the Dudley book." That's not surprising. With more than fifty years' experience in gear design and credits for five books (with translations in French, German, Spanish and Italian), numerous papers, lectures, and patents, and a worldwide reputation as a gear expert, Darle Dudley's position as one of the men to ask when dealing with knotty gear problems is unassailable.

Recently, Gear Technology *had some conversations with Dudley, not about specific gearing problems, but about "the evolution of the gear art" as he has seen it over the last half-century and where he sees the art and the industry moving as we enter a new century.*

What follows are excerpts from these conversations, ranging on topics from What Every Young Gear Engineer Needs to Know to Gears of the Future.

GT: What has been the most significant technical development in gear design and manufacturing of the last 50 years?

DD: Significant progress has been made in both design calculations for gears and in manufacturing methods. We now have calculations for gear ratings based on probability of failure and recognition of how the allowable stress for 10 billion cycles must be much lower than the allowable stress for 10 million cycles. These concepts of probability of failure and recognition of fatigue of metal over long periods of time were not used to any great extent prior to 1950.

The most significant manufacturing development has been the use of CBN

Darle Dudley

(cubic boron nitride) for grinding. CBN grinding quite often results in closer control of gear accuracy and higher rates of production.

GT: Overall, would you say gear development has been evolutionary or revolutionary?

DD: I think gearing evolves. Historically, 10 to 40 years may pass from when a new idea is first heard of to when it becomes an established trade practice. For example, I and a man named Dr. H. Poritsky first published a paper in 1943 about the feasibility of making geometric calculations for any kind of gears meshing together with fully conjugate action. But the calculations involved were very hard to do until the computer came into wide-spread use about 1960. Even then the calculations were not applied to all kinds of gears until the 1980s. In 1994 I wrote the forward to Faydor Litvin's book, *Gear Geometry and Applied Theory*, which shows how to make calculations of tooth shapes for any kind of involute or noninvolute tooth form in any kind of spur, helical, bevel, worm, hypoid or Spiroid® gear in any meshing, cutting or grinding operation.

Areas that are developing quite rapidly now are powder metal and plastic gears and ausforming of hardened steel gears. I think the space program is going to continue to have a big influence on gear design technology.

GT: Speaking of the space program, you've been involved in the military development of gearing since World War II. How have military needs, like the various war efforts we've seen and the space program, affected the development of gear technology? Have the improvements made there entered the mainstream gear markets, and how has the industry as a whole benefitted from these military developments over time?

DD: I think the space program has been the most important thing to promote rapid advancement in gear technology—and in other kinds of technology as well. After 1957, when the Russian Sputnik was launched, this country was committed to a moon landing in ten years' time, and we weren't even sure at the time we could successfully get a rocket into orbit! The massive push from the government was a tremendous impetus to develop technology quickly.

For example, we found when designing gearing for the drives of rocket booster pumps, we needed gears that could carry loads almost twice as great as 1950s gear practice allowed and yet have a reliability against tooth breakage of 1000 to 1 instead of the customary 100 to 1. The kind of focus and effort needed to get that job done taught us a lot about building better gears. We did produce the super gears we needed, but the many failures we encountered along the way also taught us a good deal about ways to enhance gear load carrying capacity that we might not have learned otherwise—or at least not learned as quickly.

GT: The geopolitical situation has changed a lot since 1957, and government spending on things like the space program is being cut back drastically. How is that going to affect gear research and development?

DD: Gear research is an ongoing thing. Sometimes the government has a program going that requires and pays for substantial gear research, as with the space program. In the last 20 years, Japan and Germany have been the world leaders in gear research. We've benefitted from their work, but in many cases, we've had to pay for not doing the development. For example, General Electric invented Borazon®, but the Japanese developed the method for using it in gear grinding. Now we import Borazon gear grinding machines from Japan and Germany, and the key patents for them are held by the Japanese.

In the future, I'd like to see us develop a test machine that can get data on elastohydrodynamic (EHD) oil film thickness up to 1 billion cycles or more. Right now there are no machines that can get this data in any reasonable period of time. But if we don't do this important development work—for lack of funds, either from private sources or the government—I suspect that it will be done in some other country, and they will get the business benefit from it. We'll only benefit second-hand.

GT: What do you see as the next great development in gear technology?

DD: We're already into the study of EHD effects as a major factor in the rating of gears for service life of more than 10^8 cycles. Even though we lack laboratory test data at 10^9 cycles, field experience is teaching the gear trade how important it is to have an EHD oil film thickness that will separate the rubbing and rolling tooth surfaces when gears are expected to survive for 10^9 or even 10^{10} tooth contact cycles.

Looking ten years or more ahead, I think we're in for surprises in gear development. Generally, engineers have a hard time guessing what's coming next. Who would have thought in the 1940s that computers would become so clever and important?

GT: What is the one technological improvement you would like to see right now in gear design and manufacturing?

DD: I'd like to see more work done on worm gears, which are running on nonparallel, nonintersecting axes. At present it's running considerably behind development in parallel axis gearing of all sorts and bevel gearing on intersecting axes. I'd like to see the research done so that worm gear strength and worm gear surface durability could be calculated and understood as well as we can calculate and understand helical gear strength and surface durability.

GT: Where do you see the gear industry in 10 years? 15? 25?

DD: Gear technology has grown rapidly in the last 50 years. Noise and vibration are now very important things in power gearing. All kinds of new formulations for both metal and nonmetallic gears have come into production. There has also been an enormous growth in technical standards, rules and codes for making gears. The ways one can manufacture a gear have also multiplied.

This has created a situation rather like the one in law or accounting. It used to be that you could do your own taxes, and

DARLE DUDLEY

EDUCATION
BSME, Oregon State University, 1940

CAREER EXPERIENCE
1940–1978. Worked for General Electric, Mechanical Technology Inc. and Solar.

1978–present. Founded Dudley Engineering Co., a gear consulting firm working with companies involved in turbine, aerospace, mining and industrial production. In 1991, most of the assets of the company were transferred to Dudley Technical Group Inc. Dudley Engineering still does limited engineering consultation as a sole proprietorship.

PUBLICATIONS
- *Practical Gear Design.* McGraw-Hill, New York, 1954, (translated into French in 1958, German in 1961).
- *Gear Handbook.* McGraw-Hill, New York, 1972, (translated into Spanish and published in Mexico in 1973).
- *The Evolution of the Gear Art*, AGMA, 1969.
- *Handbook of Practical Gear Design,* McGraw-Hill, New York, 1984. (Reissued by Technomic Publishing Inc., Lancaster, PA, 1994, and translated into Italian, 1996.)
- *Dudley's Gear Handbook*, 2nd ed., Dennis Townsend, ed., McGraw-Hill, New York, 1992.

PATENTS
- Thrust Bearing (U.S. 2,659,635), November 17, 1953.
- Flexible Coupling with Torque-Limiting Means (U.S. 2,975,620), March 21, 1961 (with E. E. Shipley)

MEMBERSHIPS
- AGMA
- ASME
- ASME Gear Research Institute
- International Federation for the Theory of Machines and Mechanisms

Dudley was the chairman of the AGMA Aerospace Gearing Committee for 19 years. He was also first chairman and the founder of the Vehicle Gearing Committee. He was also the first chairman of the IFToMM Gear Technical Committee and chairman of the ASME Research Needs Task Force for Gearing. He still serves on the Advisory Board of the Gear Research Institute.

AWARDS
- Honorary lifetime member of AGMA.
- Edward P. Connell Award (1958) for outstanding service to the gearing industry and authoritative writing in the field.
- Golden Gear Award (1966) from *Power Transmission Design* for outstanding contributions to the gear art during the last 50 years.
- Medaille D'Argent (1977) from the French Institute of Gears & Gear Transmissions.
- Worcester Reed Warner Medal (1979) from ASME for engineering contributions to gearing.
- Honorary member of Verein Deutscher Ingenieure (VDI), the association of German Engineers.
- Medaille D'Or (1986) from the French Institute of Gears & Gear Transmissions.
- Ernst Blickle Award (1994) from SEW-Eurodrive-Siftung, Bruchsal, Germany.

generally an honest man didn't ever need a lawyer. Now professional people need a tax accountant to work out their income taxes, and you don't dare enter into a contract without having a lawyer check it to make sure the words are right. The same thing is happening in gearing. Now it's very hard for the average business person or engineer to keep up technically. I think in the next decades we will see a great increase in the need to hire outside gear consultants.

For the same reason, I think we're going to see an increase in standardization for gear products. Just like you don't need to hire a consultant to buy a 100-watt light bulb, you won't need to hire a consultant to help you buy simple gear drives for simple gear jobs because standardized items will be available everywhere.

GT: We've been hearing much about the problem of young engineers coming to work very knowledgeable about computers and general engineering, but lacking much of the knowledge they need to design gears. Do you see this as a problem, and, if so, what should be done about it?

DD: I think this has become a serious problem in the last 15 or so years. The young engineers coming up have very little experience in the intricacies of gear manufacturing or the problems encountered when putting gears into service. A good gear tooth design may fail for all kinds of peripheral reasons: Inadequate bolting of the gear casing, failure of oil seals, improper or inadequate lubrication, contamination in the oil system . . . A gear designer needs a broad education in a variety of things like machinery installation, machinery maintenance and servicing, noise and vibration measurement, instrumentation and trade standards.

A young engineer interested in gearing needs to start with a basic knowledge of machine design. Then you need to know about metallurgy, heat treating procedures, the proper choice of metals for various applications, even the effect the environment will have on performance. A gear assembly doesn't perform the same way in the Arctic as it does in the Tropics or in the American desert as it does in Western Europe. All of these

considerations need to go into gear design. It's not enough to be able to plug in formulas from a computer program.

GT: Where does a young person get this kind of training?

DD: A lot of it will have to come with on-the-job training. Ideally I would have beginning gear engineers spend a couple of years working with or in a gear manufacturing shop and with field service people in a large company where failed equipment is being repaired or replaced. Then I'd have them regularly attend meetings of AGMA and ASME where technical papers on gearing subjects are presented and discussed. I would also send them to listen in on standards committee meetings so they can hear the debates and see what goes into determining gear standards.

In the meantime, I think companies would be well advised to have experienced gear consultants take a look at new designs for new projects. Even the largest companies in the automotive and electric power industries can no longer afford to keep a staff of engineers who are fully up to speed on the newest advances in gear engineering. In the cutbacks of the last few years, many of those senior engineers who had the most knowledge and the broadest experience have been given early retirement.

GT: Throughout your career, you have been very active in AGMA. What changes have you seen in this organization over the years?

DD: AGMA is becoming a world organization. Probably at some time in the future, it will change its name to AGMA International, just like the American Society for Metals did a few years ago. It's a cliché, but we really are living in a global village. The role and mission of all trade organizations now is to work toward international development and cooperation.

For example, right now AGMA is heavily involved in work with ISO to reconcile differences between ISO and AGMA gear rating standards. Eventually we'll get to the point where the ISO and AGMA standards will be fully compatible with one another.

GT: You've spent more than 50 years in gear engineering and during that time have racked up a significant list of achievements. What work are you the proudest of?

DD: One of the most important things to me was the 19 years I was chairman of the AGMA Aerospace Gear Committee. We made great progress, starting out from some very conflicting viewpoints and arriving at standards for the very demanding gearing required for the Mercury, Gemini and Apollo space programs.

I think the other area that's significant is my writing. In 1954 McGraw-Hill persuaded me to write a book, *Practical Gear Design,* which was very well received by the technical community. It's been translated into French and German and was on the market for over 30 years. Now a second edition of my *Gear Handbook* has just been translated into Italian.

Writing technical books is not very rewarding financially, but in terms of building relationships with people in the business, the rewards have been significant. Your viewpoint on technical questions gets known worldwide. Other engineers are anxious to talk with you and discuss in depth the latest technical and business developments. On that score, I've been very pleased with my writing career. ○

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