Gear Vibration: Walk, Run. . . and Now Fly!

Given the length of their history and how well established they are in such a wide range of applications, it is surprising that gears in aircraft engines are being adopted for an application that opens an entirely new research realm. The field of gear dynamics, in particular, is at the beginning of a renaissance.

Gears in aircraft engines allow the turbine to spin at its optimal speed for combustion power generation while the fan blades spin at a much lower speed for aerodynamic performance and thrust. The benefits are improved fuel economy and much lower engine noise. All of the major aircraft engine companies are actively developing such geared engines.

However, gears face a much different environment from those used in turbine engines. Weight is a far greater consideration than in most gear applications, so the gears themselves look much different. The gears spin at especially high speeds, again more than in most high-torque applications where metal gears are necessary. Additionally, the operating torques are high.

Noise generated by gear vibration has been and continues to be a concern for helicopters, wind turbines, cars, heavy machinery, mining equipment, and more. Some may wonder why we do not yet know everything about gears. While we do not, especially for the dynamics involved in gear noise problems, there has been immense progress in modeling, understanding, and analysis tools over the 20 years I have worked in the area. We see this in wind turbines and cars, especially where advanced commercial software now gives results that directly address the noise and vibration of conventional gears. Conventional gears are those where the gear bodies are essentially rigid and the compliance causing vibration is from the contacting gear teeth connecting these rigid bodies. Virtually all gear analysis is based on this modeling.

Gear failure in aircraft engine applications is catastrophic. However, with helicopters as a notable exception, most conventional gear systems do not face such consequences if components break. In fact, one of the most common conventional gear “failures” is the gears just being noisy. Vibration can also degrade performance and cause components to break, but not with the consequences of aircraft engine gear failures.

Aerospace gears fail structurally from high-cycle fatigue and cracks. Here is where the conflict with weight emerges. Lightweight gears are critical because they lead to gears with thin-walled webs (the portion between the rotation axis and the teeth) and thin rims (the material directly beneath the teeth). Some aircraft engine gears are actually tubular with the teeth

cut on the outside of a hollow cylinder. Meanwhile, these relatively flimsy gears transmit heavy torque. High stresses and fatigue become paramount issues that must be analysed accurately. These are very much dynamic as opposed to static concerns.

Lightweight, thin-walled aircraft engine gears have lower natural frequencies than conventional gears while the excitation frequencies are higher because of higher rotation speeds. Resonance becomes a dominant concern because the natural and excitation frequencies are much more likely to coincide than in conventional gears where the natural frequencies are typically higher than the major excitation frequencies. For a vibration researcher, this situation opens a whole new investigative track where the models, methods, and problems at issue are much different than for conventional gears.

Aircraft engine gears vibrate as elastic bodies due to their thin-walled structure. Models of conventional gears as rigid bodies connected by the mating teeth compliance must be replaced with models of vibrating elastic continua connected by the mating teeth. The modes of vibration are entirely different. While elastic body vibration can often be dealt with using finite element models, those models hit barriers when used for gears. They must include rotational (or gyroscopic) effects that are no longer negligible at the speeds where these gears operate. While this is simpler when the finite element model is formulated in a rotating reference frame, it is troublesome in gears because the tooth mesh is fixed in space and not rotating.

Even though the design goal is to avoid resonance, engineers cannot rely on this. They must understand and limit the severity of resonant vibration where large dynamic stresses are most likely to cause failure. Resonance leads to tooth contact loss. The tooth mesh models that have been refined over the years must be reformulated in light of this nonlinear contact and the elastic gear body deformations.

As a vibration researcher, I could not be more excited about this situation. It is rejuvenating to see such a large, new, exciting, intriguing, and practically important set of research questions appear out of the blue. This intellectually fascinating topic is emerging in the midst of the well-established, traditional field of gear noise and vibration. Everything old is new again!

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