Gear Crack Propagation Path Studies-- Guidelines Developed for Ultrasafe Design

Effective gear designs balance strength, durability, reliability, size, weight, and cost. However, unexpected gear failures may occur even with adequate gear tooth design. To design an extremely safe system, the designer must ask and address the question "What happens when a failure occurs?" With regard to gear-tooth bending fatigue, tooth or rim fractures may occur. For aircraft, a crack that propagated through a rim would be catastrophic, leading to the disengagement of a rotor or propeller, the loss of an aircraft, and possible fatalities. This failure mode should be avoided. However, a crack that propagated through a tooth might or might not be catastrophic, depending on the design and operating conditions. Also, early warning of this failure mode might be possible because of advances in modern diagnostic systems.

An analysis was performed at the NASA Glenn Research Center to develop design guidelines to prevent catastrophic rim fracture failure modes in the event of gear-tooth bending fatigue. The finite element method was used with principles of linear elastic fracture mechanics. Crack propagation paths were predicted for a variety of gear tooth and rim configurations. The effects of rim and web thicknesses, initial crack locations, and gear-tooth geometry factors such as diametral pitch, number of teeth, pitch radius, and tooth pressure angle were considered. Design maps of tooth and rim fracture modes, including the effects of gear geometry, applied load, crack size, and material properties were developed. The occurrence of rim fractures significantly increased as the backup ratio (rim thickness divided by tooth height) decreased. The occurrence of rim fractures also increased as the initial crack location was moved down the root of the tooth. Increased rim and web compliance increased the occurrence of rim fractures. For gears with constant-pitch radii, coarser-pitch teeth increased the occurrence of tooth fractures over rim fractures. Also, 25° pressure angle teeth increased the occurrence of tooth fractures over rim fractures in comparison to 20° pressure angle teeth. For gears with a constant number of teeth or for gears with constant diametral pitch, varying size had little or no effect on crack propagation paths.
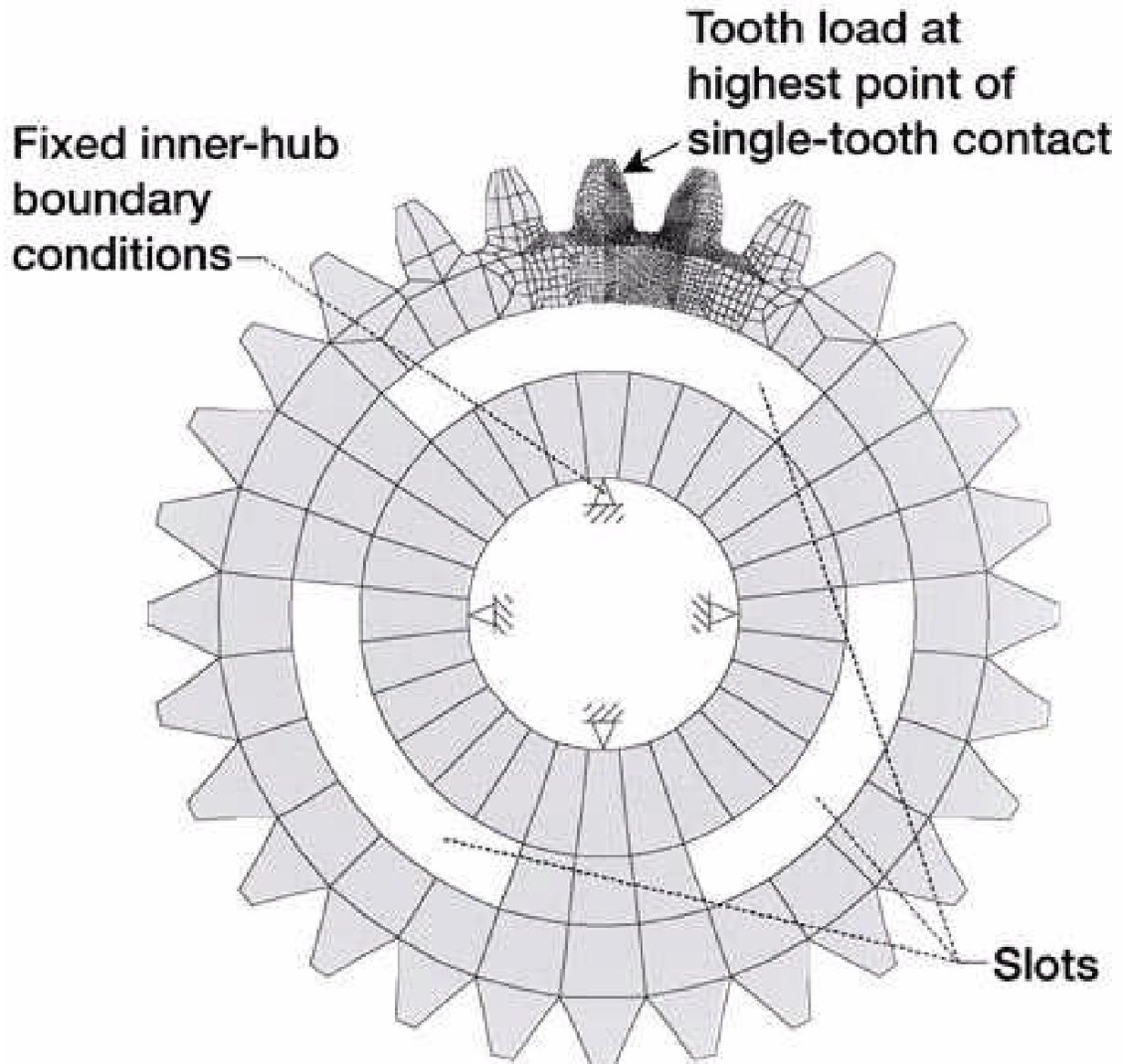
Effect of backup ratio, m_b, and initial crack location on propagation path.
Long description The gear design is the baseline used in the study. The model had 2255 plane stress, 8-node, quadrilateral elements, and 7122 nodes. For improved accuracy, the mesh was refined in the upper portion of the model (this is the region where cracks were inserted). The tooth load was placed at the highest point of single-tooth contact, normal to the surface. Four hub nodes at the gear inner diameter were fixed to ground for boundary conditions. The material used was steel. In addition, slots were incorporated in the model so that thin-rim gears could be modeled.
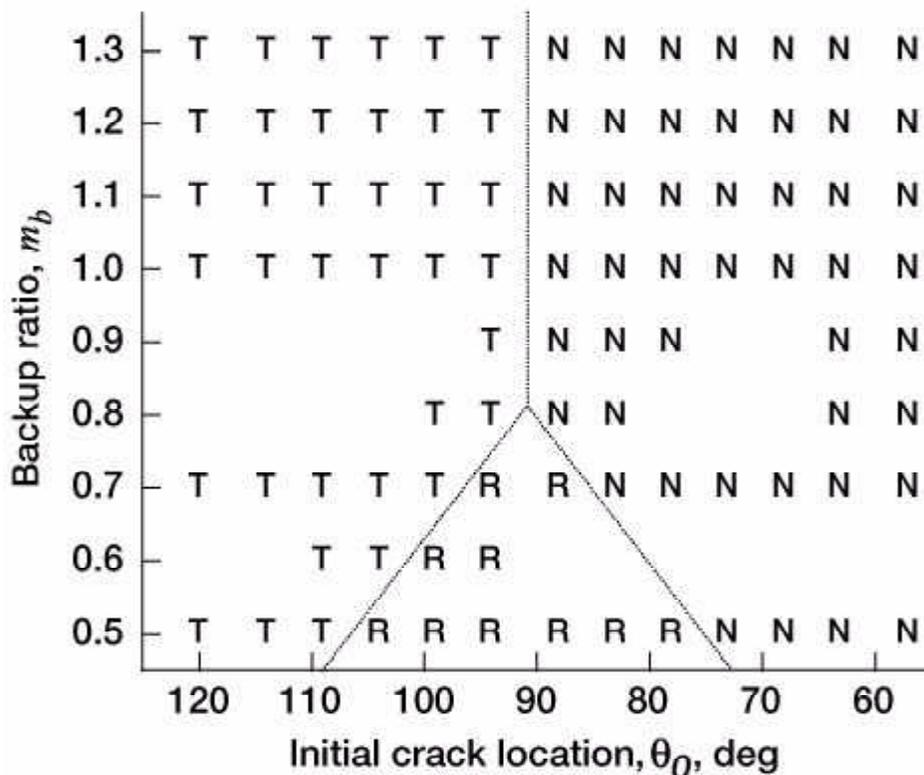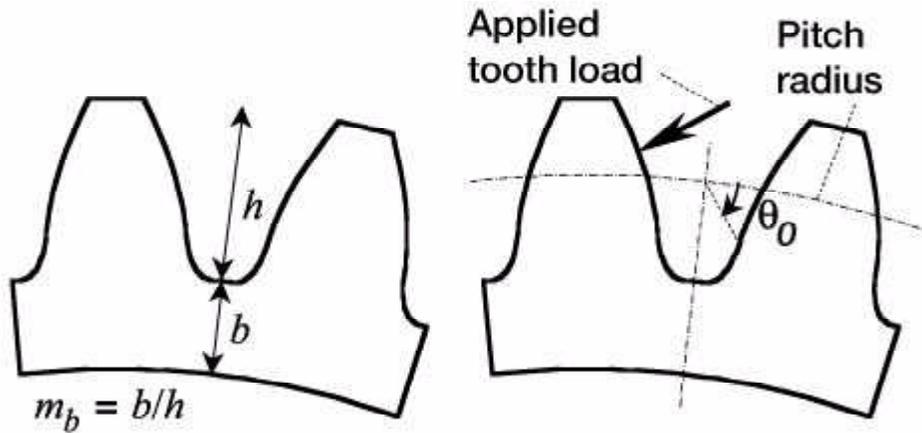
Effect of backup ratio and initial crack location on crack failure modes. Applied tooth load, 500 lb; initial crack length, 0.030 in.; stress intensity factor threshold, 5 ksi-sqrt in.; T, tooth fracture; R, rim fracture; N, no crack propagation.

Long description For the baseline gear design parameters and a backup ratio of 1.3, tooth fractures occurred for all initial crack locations. As the backup ratio decreased, the transition from tooth fractures to rim fractures occurred at a larger initial crack location angle. Thus, for thinner rims, the occurrence of a rim fracture significantly increased.

This work was done in-house at Glenn in support of the Rotorcraft base program. The crack propagation code was developed by the Cornell Fracture Group at Cornell

University.
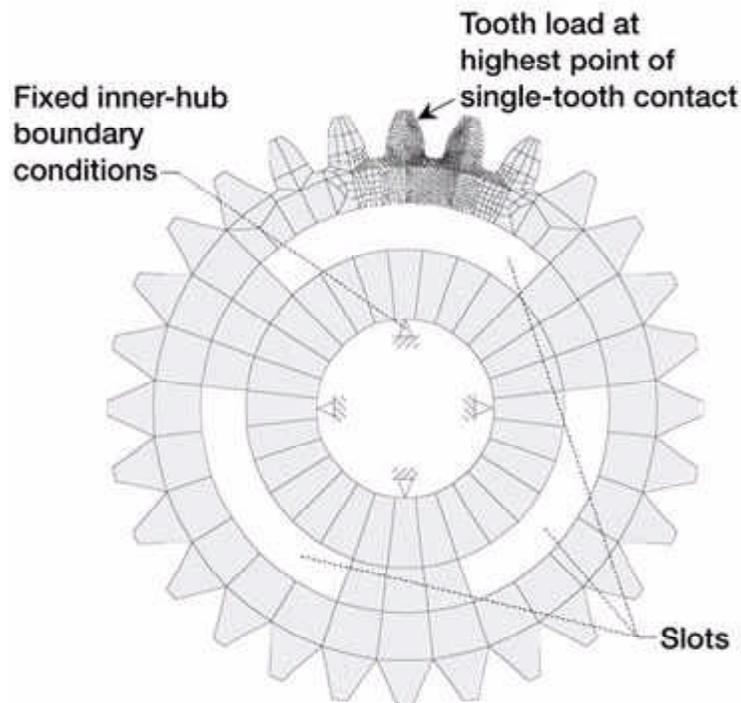
Typical finite element model of an uncracked gear used in the study. Number of teeth, 28; diametral pitch, 8; pitch radius, 1.75-in.; pressure angle, 20°; backup ratio (rim thickness divided by tooth height), m_b, 1.0.

Long description Example design map. Stress intensity factor threshold, 5 ksi-square root of in. (typical value for AISI 9310 steel, the current standard material in aerospace drive system applications). For many of the cases, the mode I stress intensity factors were less than the stress intensity factor threshold, and thus, no crack propagation occurred. For these conditions, a backup ratio of 0.8 should be used to ensure that no rim failures occur.

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