# Dynamic analysis of a thin blade moving inside a narrow fully lubricated kerf

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**Abstract**

The primary objective of using lubrication in machining is to prevent wear and overheating of the tools. Although the necessity of lubrication is well recognised, the corresponding mechanical interactions of the lubricant with the working tools are rarely taken into account in studies concerned with the dynamics of such systems. An exceptional machining operation with regard to this kind of fluid structure interaction is band sawing of thick slabs. In particular, metal band sawing serves as the motivational use-case behind the mechanical model considered here. This intriguing process is known to exhibit complicated dynamic phenomena such as torsional flexural buckling under excessive cutting forces, parametric oscillations or self excited vibrations, with regenerative chatter being the most prominent example of the latter. Band sawing features a thin structure (the blade) moving in a narrow kerf, which distinguishes it from other standard machining operations such as milling or turning.

The considered mechanical system resembles fully immersed cutting: A thin blade with constant rectangular cross section is moving through a fully lubricated narrow kerf. For simplicity sake, only transverse deflections of the blade in the kerf, i.e.: orthogonal to the vertical direction of the cut, are considered. The moving blade is modelled as an axially pre-tensioned Euler-Bernoulli beam. It exhibits transverse vibrations that dynamically alter the sizes of the lubrication gaps. These gaps' widths are the distances of the beam central axis to the left and right boundaries of the kerf; the geometry of the kerf is assumed to be ideally straight. Reynolds hydrodynamic lubrication theory is assumed to govern the fluid part of the problem, which rests on the usual prerequisites: fluid inertia and pressure variation accross the gap are negligible, fluid flow is parallel to the gap, the fluid is Newtonian and the gap is small with respect to the length of the kerf but large in comparison to the roughness of the kerf surface; cavitation is disregarded, but may be detected by the absolute pressure falling below vapor pressure of the fluid. The beam transverse deflection and the fluid pressure are the primary fields of this fluid-structure interaction problem. It is addressed numerically with an isoparametric finite element method that utilizes cubic Hermitian polynomials for interpolation purposes. The finite element implementation is facilitated by the variational form of the Reynolds equation, which induces a nonlinear coupling of fluid pressure and transverse deflections. Transient simulations are conducted for selected cases of forced or free vibrations to estimate the impact of these nonlinear effects. A dynamic stability analysis is performed for the linearised system with respect to the straight reference motion. The corresponding set of linear equations further allows to quantify viscous damping and circulatoric effects induced by the hydrodynamic lubrication films.

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The present study provides insight into the potential load bearing and damping capabilities of a properly formed lubrication film in band sawing. This may present novel opportunities to counteract detrimental dynamic phenomena or to even guide the blade in transverse direction to straighten the cut. The simplified planar problem provides a solid foundation for more intricate investigations that aim to capture some of the dynamic phenomena mentioned above. In this respect, a true 3D model of the beam with the inclusion of constrained torsion already necessitates a two-dimensional treatment of the Reynolds equation owing to the variability of the lubrication gaps in two directions.