

DYNAMIC SIMULATION AND STABILITY ANALYSIS OF MILLING OPERATION: SELECTION OF OPTIMAL TIME STEP

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1 Abstract

Machining operations involve complex physical phenomena that are still challenging to model. The simulation of machining operations by numerical methods is so complex that only academic examples (such as orthogonal cutting) can be simulated with a reasonable computing time. In order to model industrial applications, some simplified approaches have been developed ranging from linearization of the process (the stability lobes theory developed by Tlustý [7] in the sixties for turning operations and extended to milling by Altintas [2]), analysis of the stability of the differential equation by various techniques [5, 1] or by complete dynamic simulations [6, 3].

The aim of this paper is to show a framework used for the dynamic simulation of milling operations. The focus is set on the selection of the optimal time step in order to get adequate simulations for stable and unstable machining operations.

The model combines an 'eraser of matter' model [6] to generate the chip removal on the workpiece, a mechanistic model [4] for the simulation of the cutting forces and a numerical integration procedure for the vibratory simulation. The dynamic response of the system can be either identified from a modal analysis (machining on a traditional machine tool) or via a multibody approach [8] (if the kinematic is more complex such as robotic machining) in order to get the dynamic equations of motion.

Each equation can be numerically integrated at each time step using Newmark's scheme.

The general algorithm used in the literature simplifies the integration procedure by considering that the cutting forces have only a small variation between two successive time steps. It allows the use of a single iteration for each time step that reduces

the simulation time. However, some simulation showed that this simplified procedure might need extremely small time step in order to get consistent results. A enhanced procedure is thus tested where the integration procedure takes the variation of the effort into account till a convergence criteria is reached.

A simulated testcase taken from reference [5] is studied in this paper. The stability lobes diagram for the given system is shown on figure 1.

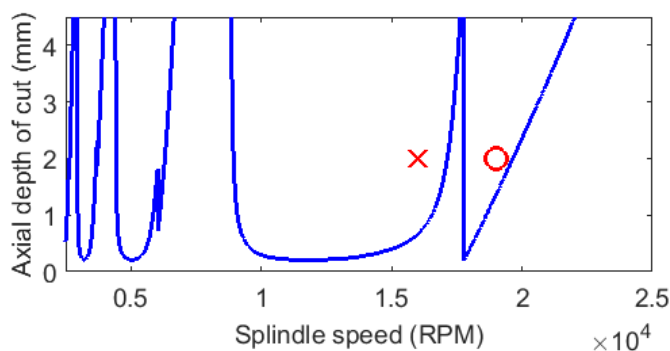


Figure 1: Stability lobes diagram for the testcase (simulation linked to Hopf bifurcation is highlighted by a cross, the one linked to flip bifurcation by a circle).

Two sets of cutting parameters are selected to highlight two different types of unstabilities: one linked to Hopf bifurcation (16000 RPM, 2 mm ADOC) and one linked to flip bifurcation (19000 RPM, 2mm ADOC).

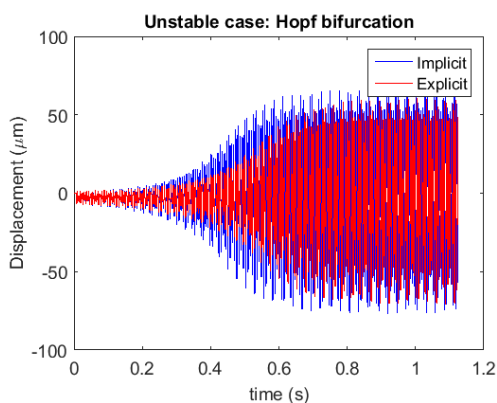


Figure 2: Hopf bifurcation.

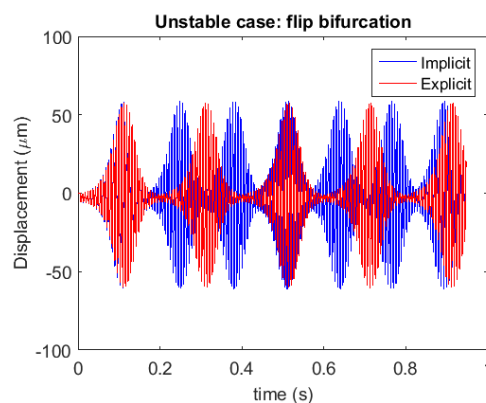


Figure 3: Flip bifurcation.

The time step is determined using the smallest value between two criteria: a geometrical one (there must be at least 30 increments per revolution of the tool where the tool is cutting) and a frequential one (there must be at least 10 increments during the smallest period of the dynamic system model).

At first, both simulations are performed with 120 time steps per revolution of the tool (geometric criteria is dominant). Figure 2 and 3 shows the comparison of the results with the implicit and the explicit integration procedure. The explicit procedure has a marginal effect on the simulation time but the results of the simulation are somewhat different.

The time step is then decreased till the results are similar between two successive simulations. It can be seen that for the explicit procedure, the initial time step is small enough. By contrast, the convergence is achieved with time step 100 times smaller for Hopf bifurcation case and greater refinement is needed for flip bifurcation (having a dramatic effect on the simulation time). The comparison will be more developed on the final paper.

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