Parallel Harmonic Balance Method: towards very large scale systems

Loïc Salles*, Jiri Blahos*, Alessandra Vizzacarro* and Fadi El Haddad*
* *Departmanent of Mechanical Engineering, Imperial College, London, UK*

Summary. This paper presents a parallel implementation of harmonic balance method coupled with continuation method. The different elements for a parallel implementation are introduced. The obtained software permits to accurately solve problem that has never been studied in this manner before. The results obtained with the proposed approach gives hints for creating accurate reduced order modelling.

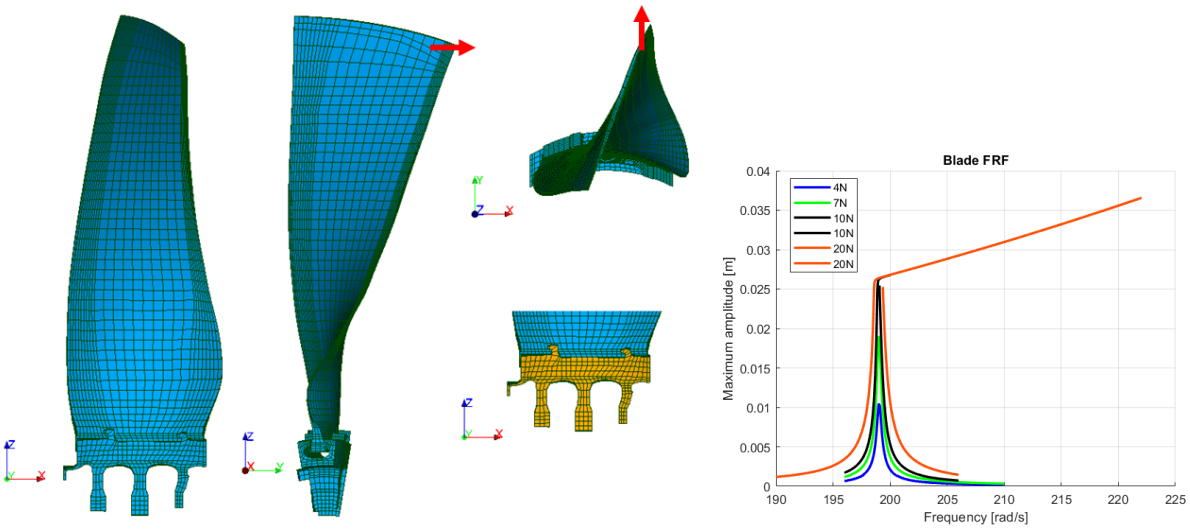

Figure 1: Fan blade with nonlinear frequency response

High-cycle fatigue caused by large resonance stresses remains one of the most common causes of turbine blade failures. Nonlinear vibration can have an important effect on the high cycle fatigue of components. Harmonic Balance Method is an efficient technique to model the nonlinear vibration of turbomachinery components. Efficient software have been developped for the last two decades but are still limited to reduced size system [5, 4, **?**].

We propose in this work to present the element to develop continuation method based on harmonic balance method for large scale system. We will explore in the paper two types of common nonlinearities: localized (contact with friction) and non-locolized (large deformation). The equation of motion and its transformation to nonlinear algeabric system will be introduced. We proposed an original implementation [6] that allows to easily treat any type of problem: frequency response, nonlinear modal analysis or limite cycle oscillation. We will then how any type of localized nonlinearities can be treated using harmonic balance method and alternating frequency time procedure [3]. We will present how the computation of nonlinear forces can be parallelised using both OPENMP and MPI programming language.

In a second part the paper focus on the non-localized nonlinearities and their implementation in the Finite Element framework. A C++ code has been developped and solves the nonlinear HBM problem in parallel, using MPI. A 3rd party software package is used to load and distribute a mesh. Standard finite element scheme is then used to assemble the sparse system matrices (mass, stiffness, damping) in parallel using CSR format. Nonlinearities are added using the alternating frequency time (AFT) procedure. Frequency domain dofs are organised in a way that keeps them on the same MPI rank as their corresponding mesh nodes to minimise necessary communication. To solve the nonlinear HBM problem the Newton-Raphson iterative algorithm is used. For the underlying linear problem, we used a 3rd party software package based on parallel sparse implementation of the LU decomposition [1]. The code results have been verified against previous results presented in the scientific literature. The code has been tested on multi-million degree of freedom problems. A decent speed-up was obtained for number of MPIs up to approx. 100 MPI ranks.

Several numerical results on academic problems (cantilever beam and clamped-clamped beam) will illustrate the proposed method and gives hint for creating reduced order model. It will be shown that care has to be taken when creating reduced order model for structure in large deformation.

The paper will finish with recommendation about future work needed to develop more scalable continuation methods for nonlinear vibration analysis.

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