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[Extended Abstract]

Assessment of performance variation on the axial and radial forces in turbopump configurations for liquid rocket engines

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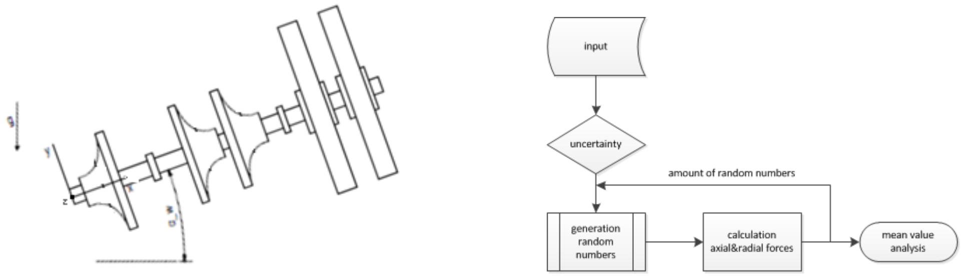
Introduction

In modern liquid propellant rocket engines turbopumps (TP) are inevitable to provide the combustion chamber with a high propellant massflow at high pressure. Both are necessary for the performance of the engine and a efficient, lightweight stage e.g. due to a reduced weight and pressure inside of the tanks. In order to meet the engine requirements in terms of performance the turbopump assembly (TPA) must be able to operate at high speed, work over a wide operational range, and has a high power density. Depending on the configuration and the possible engine cycle, a TPA consists of inducers, pumps, turbines, a seals, bearings, and shaft system , and a housing with flanges. Each part is designed to operate under harsh boundary conditions and a low system weight. In order to minimize the stresses on heavily loaded parts like the bearings, the forces acting in radial and axial direction should be estimated. Further more, during the design process of the TP parts, the balance of the axial forces can be achieved. Therefore, the aerodynamic and hydraulic forces acting on each part of the TPA have to be calculated and brought into relation. The results are an important starting point for further design details and first rotordynamic analysis.

1. Methods

A tool has been developed to estimate the forces acting on inducers, impellers, and turbines in both axial and radial directions. The calculation of forces acting on the hydraulic parts in axial direction are based on Gülich [1], where in axial the impulse, pressure forces acting on hub and shroud, and unbalanced axial force on shaft are considered for no flow through at a first step. Radial forces are determined only for the volute with a simple method proposed by Stepanoff [2]. Aerodynamic forces on the turbine are estimated considering impulse forces and if present pressure difference. Additional moments due to partial admission of the turbine can be taken into account, too. Forces to due unbalance of the parts are roughly evaluated. Finally, the weight of each part is calculated depending on the orientation of the TP in the engine and the acceleration of the rocket stage. Based on the dimension and position of the parts, the resulting bearing forces are calculated.
The different configurations of existing TP has been evaluated in a small literature review and the tool is able cover most types of modern TPA featuring inducer, up to three stage impellers for both

oxidizer and fuel together with a maximum three stage turbine on one shaft. In figure 1a an example of a possible TP configuration can be seen, the used convention for the acceleration and orientation can also be found there.



(a) Example of turbopump configuration

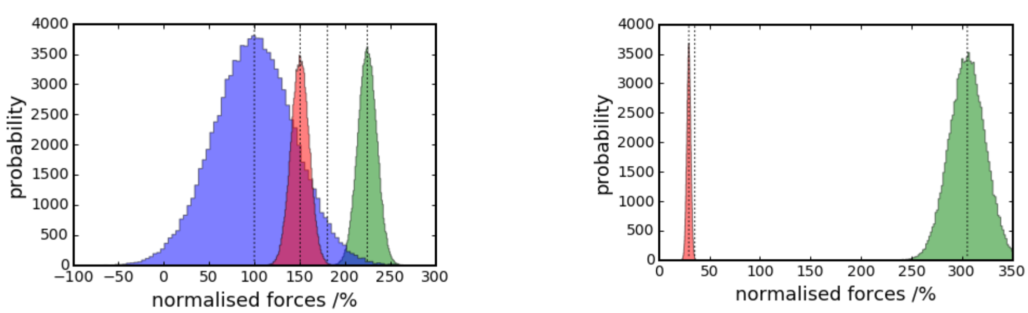
(b) Cycle of random number generation

Figure 1. Method description

A main feature of the tool is the generation of random numbers to take the uncertainties of performance values into account. This approach is necessary in an early stage of design. Each input value for the calculation of the forces can be provided with a certain range of uncertainty and a set of random number with a Gaussian distribution is created. The cycle of random number generation is shown in figure 1b. The uncertainties can be set globally, but also individually to accommodate the detailing and reliability of the input values. This function can also be used to assess the influence of input values on the entire design. A detail description of the tool can be found here [3]. An enhancement of the tool is the interface to a simple bearings stiffness tool based on a general theory for elastically constrained bearings [4] and the generation of input values for a dry rotordynamic analysis, which can be started directly from the tool.

2. Preliminary Results

The mentioned method has been applied during the design of a liquid rocket expander cycle upper stage engine LOx turbopump with roughly 120 kN thrust. The configuration is subject of the KonRAT project. A project to build up competencies in the development of TP. The design method and configuration is described here [5]. Results for a global setting of uncertainties a presented in figure 2.



(a) Fixed bearing

(b) Loose bearing

Figure 2. Preliminary results of bearing loads, blue: axial forces, red: radial forces statically, green: dynamic radial forces

In the full paper, the influence of the input values on resulting axial and radial forces are assessed and discussed based on the generation of random number. Geometry variations are performed and evaluated in terms of loads and their impact on rotordynamics.

References

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