Shape Optimization of a Metallic Flywheel using an Evolutive System Method:

Design of an Asymmetrical Shape for Mechanical Interface

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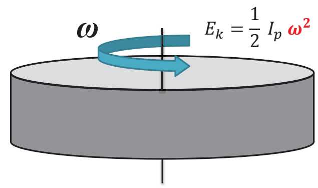
Introduction

The use of **flywheels** for **energy storage** is a proven technology in different applications:

- **Grid power quality**, where it is needed for limiting fluctuations in the available power;
- **Uninterruptible Power Supplies**, which grant continuous power in the event of a blackout;
- **Renewable sources**, where power generation is not stable nor controllable;
- **Energy recovery**, for regenerative braking on cars, trucks or trains;
- **LEO satellites**, which must store energy to survive on the shaded part of the orbit.



The stored energy increases rapidly with the rotational speed

Objective

The aim of this work was to obtain the lowest mass possible on a metallic flywheel, while ensuring mechanical integrity at high speed.

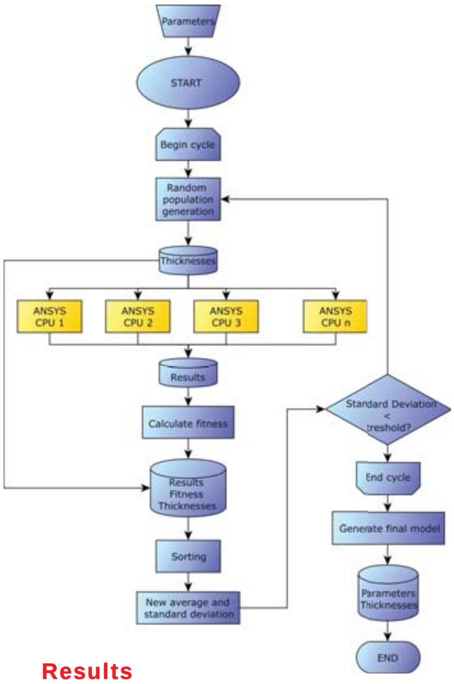
In an **inertial battery**, the flywheel rotates at high speed, to leverage the more efficient increase in energy density.

Lighter rotors are more easily suspended on **magnetic bearings** than heavier ones. Weight is especially an issue on vehicles and satellites.

Metallic flywheels present practical and economical advantages over composite materials:

- More suitable for **vacuum application;**
- Lower material **cost**;
- No **stress relaxation** over time.

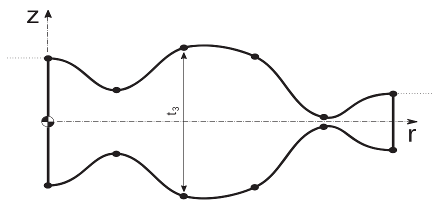
Optimization procedure



The model is **2D axisymmetric** implemented in **Ansys APDL**.

The flywheel profile is composed of two **splines**, described by a number of points. For each of those, the **r** position is fixed while the **z** position, or thickness, is determined by a **parameter**. Up to twenty points per side were used. A **free meshing** algorithm allows to avoid very distorted elements.

The whole optimization algorithm is written in **Matlab**: an **Evolutive System** algorithm takes care of the optimization process. It allows an **effective** optimization also when dealing with a complicated case.



Example of an initial profile, described by six parameters

Each profile is an **individual**, which has its own **genome**, i.e. the set of parameters that describe it. The average and standard deviation of the parameters in the genome of every individual is used to describe the **population** in the respective **generation**.

All the individuals of the population are evaluated in **parallel** on several single core batch instances of Ansys. The **results** are gathered inside Ansys, and they will be used to evaluate the fitness.

The **fitness** is a measure of how well any individual is suited to the task. It is a combination of objectives and constraints used to find the best individuals for **reproduction**.

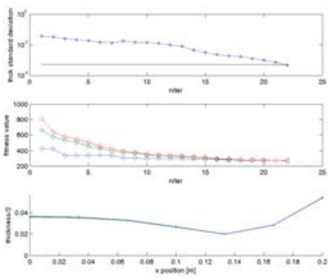
They will contribute more on the **new average** values of the genome of the next population than the others, thus spreading more their genes.

The method allows to **add parts** on the profile that are not directly involved in the energy storage function, such as a **mechanical interface** for the spindle. **Even if this lies only on one side.**

Results

In this work a novel **optimization** approach has been devised and applied to the multi-parameter optimization of a high performance metallic flywheel. It is a **DSO** (Deterministic Structural Optimization) performed via an **Evolutive System algorithm**.

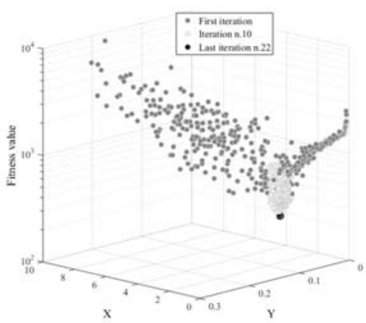
The **convergence** over the generations can be seen in the following graphs:



On the left, the standard deviation of the population's genome becomes lower than a threshold, thus **halting** the optimization. The **fitness** value gets lower to the point where no further improvements are seen.

On the right, the **fitness value** is represented in a 2 variable domain. This is reduced from 15 parameters through non linear combinations.

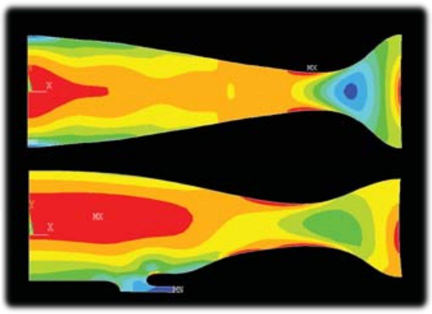
The correlation between the resulting two parameters was kept as low as possible.

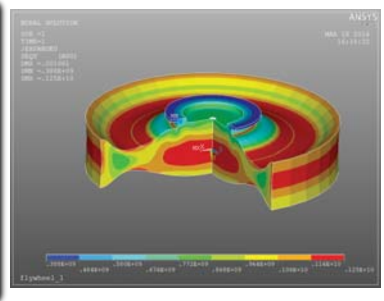


The effect of the **design variables** has been investigated on a symmetric profile: stored energy; speed; radius; material density and strength.

By adding a fixed part on one side of the profile, representing a **mechanical interface**, the algorithm was nevertheless able to obtain an **optimal solution**.

The results of the presented study were used in the development of a **commercial device**.





Conclusions

The optimization procedure effectively leads to a low mass result for a target stress, thus ensuring mechanical integrity. The procedure is also suitable for the design of asymmetric shapes.