M.A.D Battery

(**MA**gnetic spring **D**isk)

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***Abstract*—Integrating energy storage systems (ESS), in large management of energy production is probably one of the holy grails of the present day. The existing solutions are not ready to handle the problem and, not only the environment, but also the economy are starting to feel the consequences. Progress is being made to improve the current technologies, to make them viable for such applications. This paper explores a new concept of ESS and uses the EMS software to run some studies in order to find the best suitable design before any model construction or experiments.**

I. Introduction

THE contribution of electric energy has increased over the years. In 2017, about 18% of the energy consumed in the world was on the electric form [1] and it is estimated that this parameter reaches 34% by 2025 [2]. In fact, the versatility and usefulness of this form of energy are evident. As electricity begins to represent an increasing share of our society, we will expect the problems characteristic of this sector to be critical in various areas of our economy. The problem is the production policy for direct consumption. Nowadays production in power plants has to answer in real time to more or less predictable fluctuations in consumption. Peaks in consumption are often 10 times higher than the daily average and our production systems have to be naturally oversized to supply all periods [2]. One of the major challenges nowadays is to design energy storage systems (ESS) capable of eliminating the instability caused by unstable consumption swings, thus reducing the waste of resources and avoid oversizing power plants. The problem has grown even more with the emergence of renewable energies which, because of their unpredictable nature and difficult control, continuously produce unpleasant and often difficult to manage energy waste. In Germany, as in other European countries, the recent investment in renewable energy has already forced the sale of electricity at negative prices [3]. The integration of ESS into renewable production systems, such as solar energy, could also dramatically increase the viability of renewables over fossil fuels. However, unfortunately, there are still not much ESSs capable of being integrated in the large electricity production network. The best solution is found in pump hydro technology, which accounts for 99% of the management systems [4].

In the context of the master's thesis for the mechanical engineering degree at the University of Coimbra, this report resumes a section of the final paper that concerns the experience with EMS [5] software in exploring a new concept of Energy Storage System. The main goal is to study the feasibility of a mechanical battery based on interaction forces between permanent magnets and some of the possible configurations.

II. Study Designs

The battery will work by the principle of a spring. While charging, energy will be spent to bring opposing pole permanent magnets closer together against the magnetic potential. The moving parts will now be locked. To retrieve the stored energy the lockers are released and the magnets will force the mechanism to move to the initial position. The kinetic energy generated must then be converted into electricity.

The challenge here is to conceive an equipment capable of storing the most possible energy in the fewest space possible. Two designs were studied using the EMS software being them the spiral and the linear magnetic spring.

SPIRAL SPRING

This configuration consists in an internal moving part (rotor) and a hollow cylinder stator, both built with an arrangement of small disk magnets.

The idea is that, during charge, the rotor will spin and move forward, in a screwing motion, always against the magnetic potential. In discharge, the stator magnets will force the rotor to unscrew, returning the stored energy. In other words, what we will be looking for with EMS software, is a stator magnetic arrangement able to always force the rotor to spin in the same direction in every step of the way. The resulting torque on the rotor must always be positive or always negative in order to ensure that while discharging, the rotor will go all the way back to the initial position.

The stator is made of tow ring arrangements, one above the other, each one with 6 facing north permanent magnets and 6 facing south (Fig 1.). The rotor will also have 12 magnets with exactly the opposite arrangement of the lower stator ring so that the initial position on charging would be the most stable and the final “completely changed” position (where the rotor will then be fixed), would be the most (maximum potential energy state).

The thread pitch is made so that the magnets on the rotor go from being in the same level of the lower stator ring to the level of the top ring after a full rotation (Fig 2.).

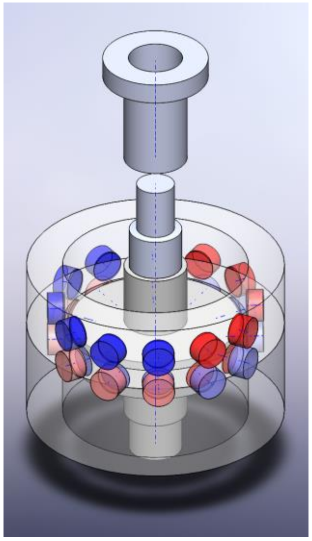

Figure 1. Final Solidworks model for EMS testing. Spiral spring

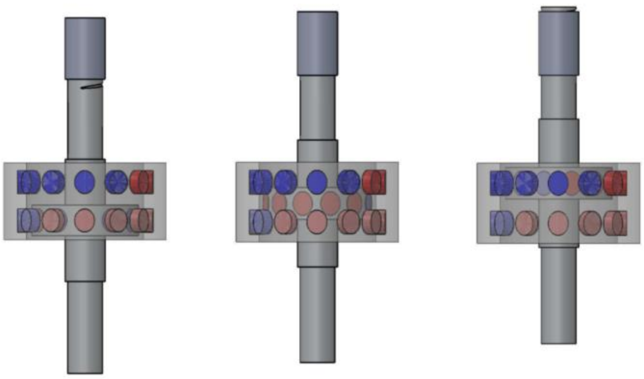

Figure 2. Sematic representation of the charging motion. Spiral Spring

The EMS study will evaluate the net torque on the rotor for different stator arrangements. In order to do so, the upper stator ring will rotate 45 degrees for each study making a total of 8 magnetostatic analysis (Fig 3.).

To simulate the different positions of the rotor during the charging motion, a parameterization will be used for every 5 degrees of turning, starting at 0 degrees (rotor aligned with the lower stator ring) and ending at 360 degrees (rotor aligned with the upper stator ring. Fully charged battery).

Other configurations were also tested based on the spiral spring concept. One worth to mentioned is build only with north faced magnets and a big ring magnet as a stator (Fig 4.)

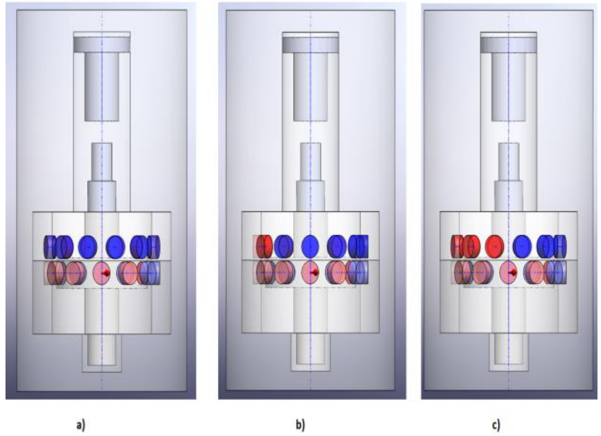

Figure 3. three different upper ring arrangements. Rotation of a) 45 degrees, b) 90 degrees rotation and c) 135 degrees.

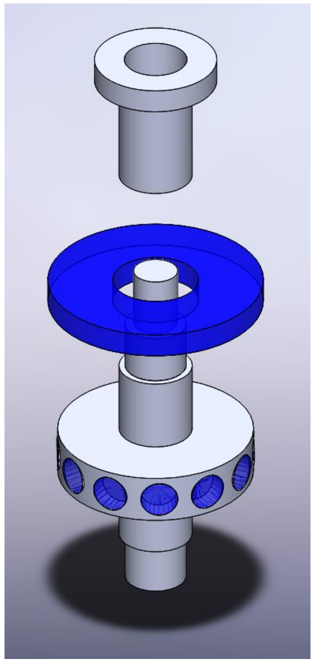

Figure 4. Configuration with ring magnet as stator

LINEAR SPRING

Another possible approach is to get back to the simplest possible configuration where tow magnets, faced with the same pole, are brought closer together in a linear motion and then released so that the energy spent is restored. One disadvantage of this configuration is that the compacity could somehow be compromised compared with the “spiral spring” approach. Also, knowing that the repulsion force between permanent magnets dopes exponentially with the distance, its expected that the force output of the battery will only be meaningful in a short distance of interaction. Many changes were made to this configuration so that we could overcome those disadvantage but, since that progress had not much to do with the EMS software experience, they won't be mentioned in this report.

There are two designs that suit this concept: the first is made of two rectangular pieces, the “poles”, filled with one or more faced north magnets. One pole is fixed while the other is free to move and attached to a rack and pinion mechanism (Fig 5.); the second design has one moving pole between tow fixed ones. When charging the battery, the moving pole moves away from a north-south magnetic interaction and towards a north-north, once again against the magnetic field potential (Fig 6.).

Again, the studies were based on magnetostatic analysis with parameterization. This time the parameter was the distance between repulsive poles.

In both cases, with the EMS simulations, the only interest is to study the shape of the curve Force-Displacement. The magnitude of the force is not a main factor since the type of magnets were not yet determined. The studies will serve as a term of comparison between different configurations in other to find the most suitable for the application.

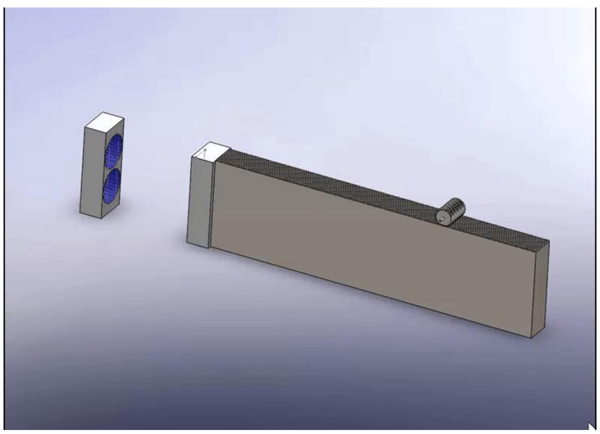

Figure 5. First linear spring configuration with tow magnets in each pole.

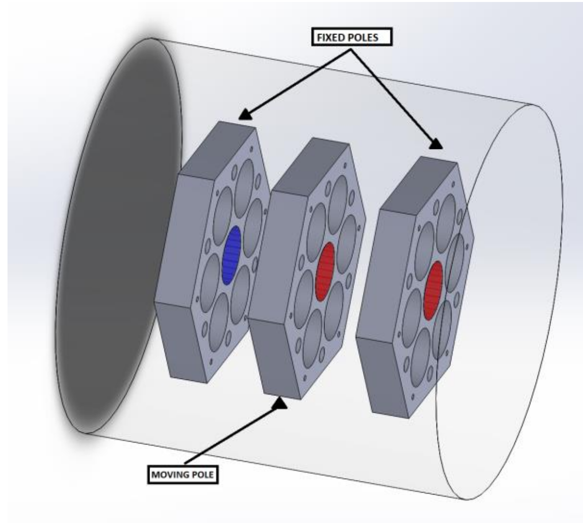

Figure 6. Second linear spring configuration with only one magnet in each pole.

III. SIMULATION RESULTS

All the simulations were focused on studying the net forces and torques on the moving parts so the “virtual work” tool was crucial. The torque center was always at the origin.

No noticeable mesh controls were made and the mesh density was almost ever the software standard.

The materials used as well as they’re properties are shown in the Table 1.

	Conductivity [Mho/m]	Relative permeability	Coercivity (A/m)	Remanence (Tesla)
Nylon	0	1	-	-
N42	1.1e6	2000	-	-
Air	0	1	900000	1,3

Table 1. Material properties

The results for the spiral spring concept showed that none of the studied configurations work according to the objectives. In fact, all stator arrangements tested for the hollow cylinder design proved to produce a torque on the rotor that changes from positive to negative orientations during the charge and discharge of the battery. As result, with the proper load applied on the energy conversion system, the rotor would probably stop in a intermediate position (around 80, 180 or 270 degrees), causing the battery to restore only a small part of the energy spent to charge it (Fig 6.).

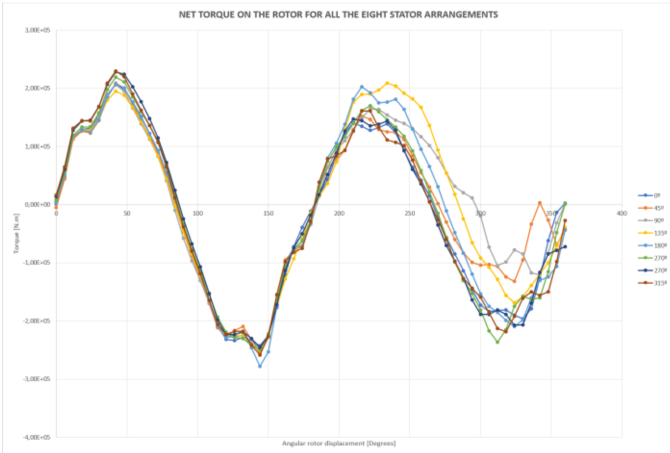

Figure 6. Results for spiral spring, hollow cylinder stator configuration.

The Fig 7. shows the magnetic flux density 3D graphic for the ring stator configuration who also results in the same changing sign torque problems as the previous study.

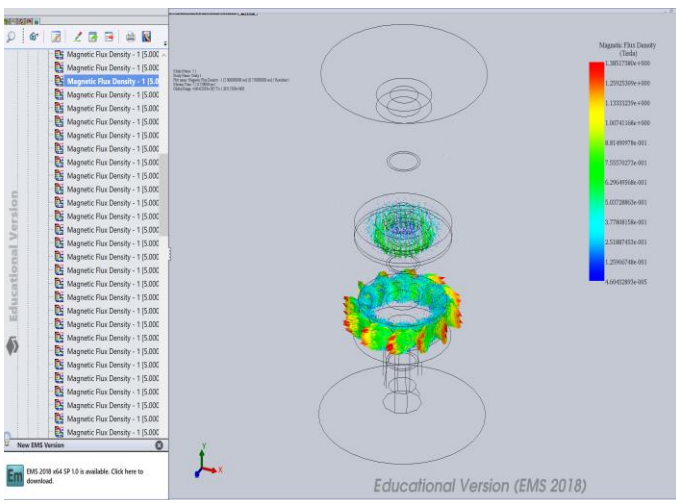

Figure 7. Results for the magnetic flux density on the ring stator magnet configuration. In the step shown it can be clearly seen the net torque orientation on the rotor

For the linear spring concept, the results were not much surprising but still useful to compare the curve shapes and force magnitudes (Fig 8-9.).

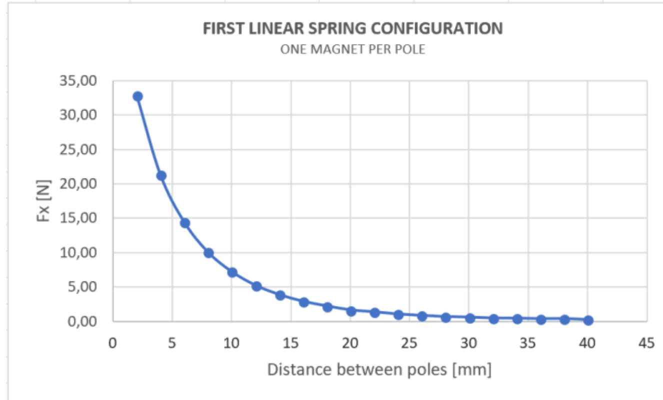

Figure 8. Results for the first linear spring configuration

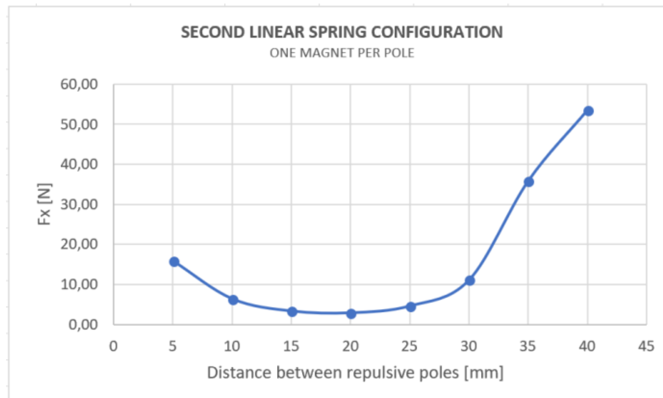

Figure 9. Results for the second spring configuration

IV. Conclusion

The EMS software proved useful to exclude some possible designs, but overall the experimental approach may be handier for this type of project.

The second linear spring configuration produced interesting results that can be, with some adjustments, similar to a explosion piston motion. In that case, the energy conversion mechanisms are already familiar, making this design probably the best one between the summery of the studies.

References

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