REGIM
Design of a Regenerative Damper for Agricultural Machines

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Executive summary

A damper is a device that suppresses vibrations and dissipates their energy in the form of heat. The aim of the REGIM project is to bring an innovative regenerative damper into the agricultural sector. Regenerative dampers recover the kinetic energy of the vibrations and convert it into readily usable electric energy.

REGIM is part of a bigger initiative driven by Frandent Group, an Italian company specialized in the production of agricultural machines. Frandent promotes the continuous improvement of its machines through equipment that requires lower energy consumption and increases productivity. REGIM aims to design a regenerative damper that could substitute the conventional ones already installed on the agricultural machines, bringing the added benefit of energy recovery, thus increasing fuel efficiency.

The project involves the optimization of the device with regards to several physical phenomena (multiphysics) and the design of the electrical circuit to interface the device with a battery (power electronics).

The integration of a regenerative damper on agricultural machinery supports the innovation wave of sustainable mechanization and electrification. In this regard, the project acts towards the global effort of the Sustainable Development Goals by fostering the Goals of Zero Hunger (2), Affordable and Clean Energy (7) and Responsible Consumption and Production (12).

Key Words

Energy harvesting; agricultural machines; electrification of agriculture; multiphysics; power electronics;

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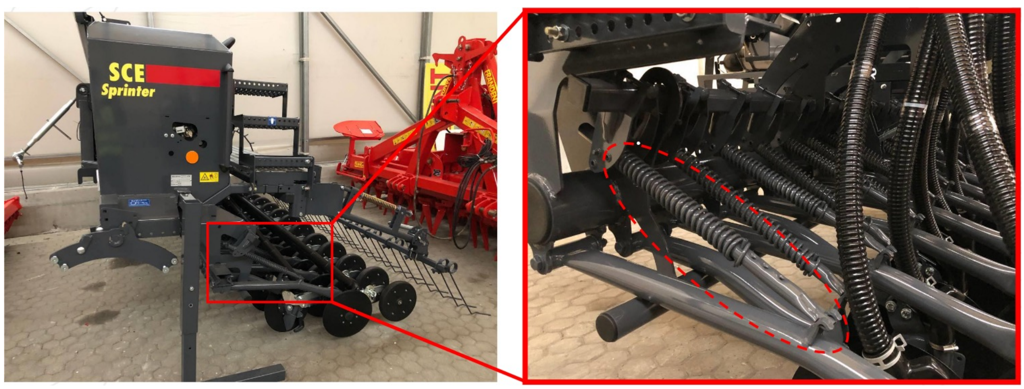
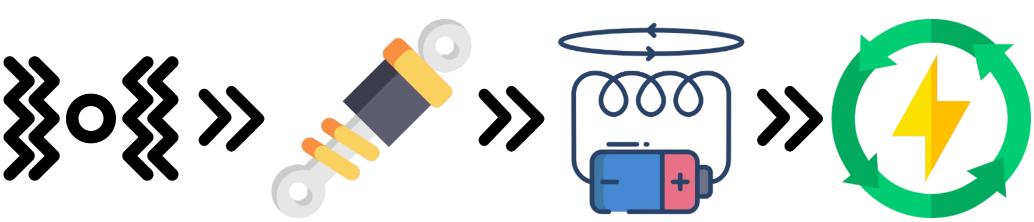


Conventional Non-Regenerative Dampers

REGIM Regenerative Damper



Project description written by the Principal Academic Tutor

A typical Regenerative DC-damper (RDC-damper) is composed of a slider and a stator. The former is composed of iron poles and magnets, while the latter consists of copper coils encased within a cylindrical back iron. A relative movement between the two parts generates an induced voltage across the coils, which, with proper connection of the coils terminals to an electrical circuit, produces a current flow. The resulting **power**, subtracted from the mechanical motion, can properly **collected and stored** for further use of interest, instead of being dissipated in heat, like in conventional dampers.

Previous multiphysics computer modeling studies of the research group attested that electric vehicles may enjoy significant benefits from an integral RDC-damper: the same concept can be naturally extended to agriculture machine with even greater benefits due to the greater available mechanical energy during operation.

The design of a **new RDC-damper for agricultural machines** must take into account the typical frequency range and stroke escursion of the oscillations, and should **maximise the damping force and the harvested power**. The project requires a highly **multidisciplinary team**, in which diversified backgrounds in mechanical engineering, electromagnetism, power electronics and control are needed to achieve a comprehensive analysis of the system. The developed approach is intended to be as general as possible, to extend its validity to a wider range of industrial applications.

Thanks to a 30-year experience in the multiphysics design of materials, processes and devices, and to the availability of a **novel test rig**, the research group is confident in achieving the project objectives. A **CAD-based model** of a new damper prototype and the design of a proper power electronics converter are the targets of the project. A **prototype** will be fabricated and tested under realistic operating conditions. The experimental phase is meant to enhance the reliability and prediction capability of the built design models, to make the RDC-damper converge to an optimal configuration for the prospected application.

Team description by skill

The REGIM team is composed of 6 engineering students, specialized in different sectors. The team composition was dictated by the high technicality of the project, which required both physical and mechanical knowledge, as well as expertise in electronics and control.

Andrea studies Mechatronic Engineering, specializing in control systems design. He contributed to the multiphysics simulations, with a focus on the optimization of the damper's geometry, as well as to the execution of the Processor-In-the-Loop tests.

Francesca studies Industrial Production and Innovation Technology Engineering. Her background enabled her to support the team in the management of stakehodlers, procurement and requirements definition.

Lorenzo studies Physics Engineering, specializing in electromagnetism and optics. This background helped him in the multiphysics simulations, with a focus on the magnetic behavior of the device.

Omar studies Aeronautical Engineering, specializing in aerodynamics. His experience with numerical modelling helped him in the multiphysics simulations; moreover, his experience in experimental fluid mechanics was crucial for the prototype testing and data collection.

Stefano studies Electronic Engineering and is specialized in power converters design. Thanks to his Bachelor degree in Physics Engineering and his current studies, he contributed to the physical and mathematical modelling of the electrical machine and to the electronic control design.

Duc Tan studies Electronic Engineering and is specialized in microelectronics. His contribution includes setting up and validating electronic circuits on which the damper's control scheme is implemented.

Goal

The aim at the core of the REGIM project is to design a **regenerative shock absorber capable of harvesting vibrational energy** and transforming it into readily available electrical energy.

The proposed solution consists of a tubular electromagnetic damper with optimized geometry for energy harvesting from agricultural machines. The damper needs to comply with the geometrical standards of the conventional dampers in use on agricultural machines and appliances and to the electrical standards of the battery of the vehicles.

The agricultural field appears ready to accept substantial innovation in terms of sustainability: REGIM aims at providing a cutting-edge technology to push for a more pervasive **electrification of the agricultural field**.

Frandent Group, an end-user leader in the construction of agriculture machines and appliances, will benefit greatly from this innovation to achieve their goals of increasing productivity of their machines and decreasing the sustainable impact.

Understanding the problem

Only **one fifth of the energy contained in the fuel is actually used to drive vehicles**, while the remaining portion is dissipated in the form of heat, noise, and vibrations. In this regard, vehicle suspensions have a substantial influence on fuel efficiency. If part of the dissipated energy were recovered and made available, this could greatly increase the overall energy efficiency.

Energy harvesting has been a hot topic for research in the last decades, as a way to recover part of the lost energy, and many solutions have been demonstrated and commercialized, mainly in the automotive sector. Energy recovery from the braking systems of cars is nowadays a common technology in electric and hybrid vehicles. Nevertheless, energy harvesting from vibrations is still at an early research stage; moreover, **regenerative dampers have not yet been investigated for agricultural machines** or appliances.

The main constrains that limited the diffusion of other regenerative dampers and might slow down the development of our device lie in the high production cost of the most effective solutions and the lock-in of current conventional dampers.

In addition, the optimization of the device needs to account for several physical phenomena and to comply with many different constraints both in the dimensioning of components and in the interface between the device and the electronic control circuits. The interplay between these factors makes the modelling and optimization of the damper a challenging task, requiring **multiphysics tools coupled with electronic circuit analysis**.

Exploring the opportunities

The fact that energy harvesting in the agricultural field has not yet been explored opens great possibilities for REGIM in terms of **market positioning** and standardization of components. On top of that, the **cooperation with Frandent** will benefit the team both for the optimization and testing of the prototype and for the early stages of its commercialization.

The regenerative damper can be applied to agricultural machines to improve fuel efficiency, or to passive attachments to extract energy, contributing to create a positive energy balance.

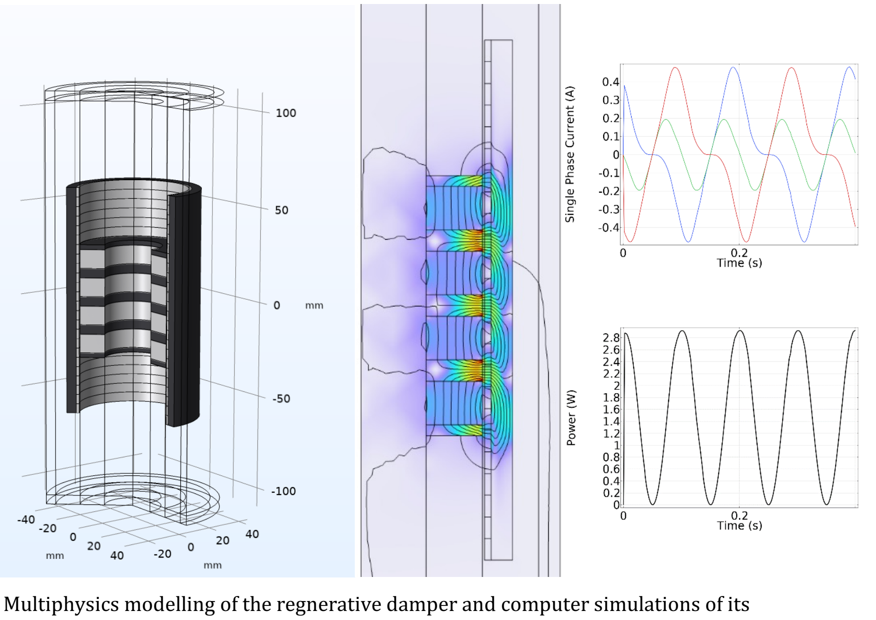
The competences of the team members and the tools at their disposal allowed them to investigate the relevant phenomena involved in the energy harvesting process, and to develop the required power electronic circuits. The availability of data by Frandent Group's own measurement campaign can greatly boost the optimization and design of the damper during computer simulations.

Moreover, the availability of a novel test rig by Politecnico di Torino allowed to **test the developed prototype**, thus providing crucial feedback for the optimization of the control.

Generating a solution

Due to the intrinsic multidisciplinarity of the project, the development of the prototype required the combination of parallel and joint working approaches. Two broad objectives were identified: **design of the physical generator** based on multiphysics simulations, and **design of the electronic interface** with the battery to be recharged.

Given the application in agricultural machines, the most suited solution was found to be a direct-drive, linear, semi-active damper with a sensored control based on digital controllers. In order to contrast the issue of lock-in of the current technology, **REGIM's device needs to easily replace the conventional dampers already installed in all machines**, fulfilling the existing damping function while also providing the additional benefit of energy harvesting.

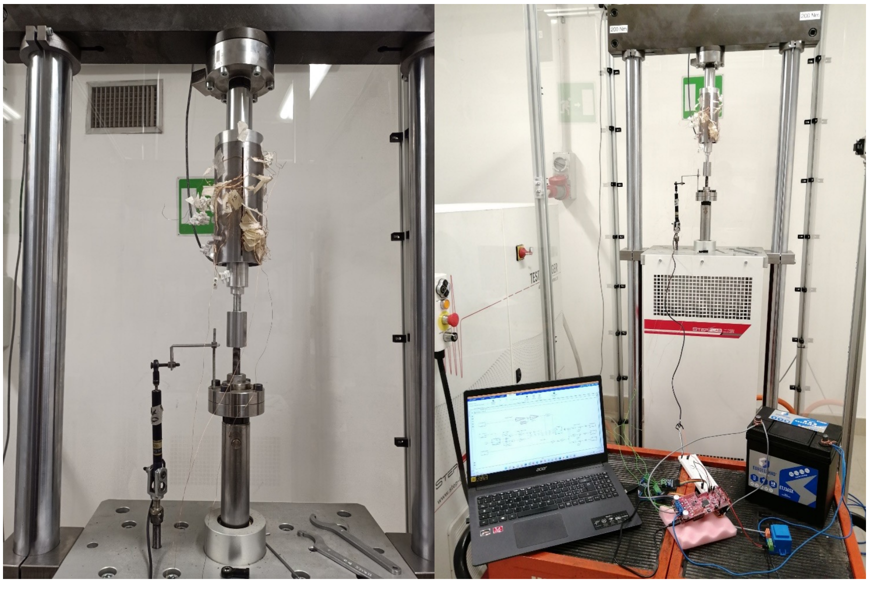


Multiphysics modelling of the regnerative damper and computer simulations of its operation.

The design of the materials and components indicated that, under the geometry constraints dictated by the size of current dampers, 4 axially magnetized NdFeB permanent magnets, separated by permendur (FeCo) spacers, allow for the highest efficiency in energy harvesting. The magnets are mounted on a tube made of an aluminum alloy and the whole structure is enclosed in a back iron made of 3.2 wt% silicon steel. The **optimization of the dimensions** of the aforementioned components was carried out iteratively, yielding the configuration that **maximized the recovered power**.

Concerning the power electronics, a conventional 3-phase inverter was selected as the most natural solution to interface the electrical generator and the battery. The team focused on an **ad-hoc control design** based on a microcontroller, which can be easily reprogrammed, providing great versatility. The Field-Oriented Control for the instantaneous regulation of the phase currents was considered the most suited solution. To ensure general validity, the team performed an integral and parametric design of the closed-loop control in all its blocks. An on-site testing and post-processing allowed to extract data referred to the maximum amplitude and frequency bandwidth of realistic vibrations of a tractor chassis driving on an agricultural soil.

The optimization dimension results were translated into a **manufactured prototype and a complete testing setup** was developed to experimentally validate the design in both its multiphysics and control aspects.



Experimental setup developed for the testing of the damper on the new test rig available at Politecnico di Torino.

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