Magnetoelastic Energy Systems For Even More Electric Aircraft

Publishable Executive summary

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Contractors

The MESEMA project (1st of January 2004 – 30th of June 2007) brought together 18 academic and industrial institutions from 8 countries.

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	European Research and Project Office GmbH		EUROCOPTER DEUTSCHLAND GmbH
	Universität des Saarlandes		National Institute of Research and Development for Technical Physics
	Seconda Universitá degli Studi di Napoli; Dipartimento di Ingegneria Dell'Informazione		Kungliga Tekniska Högskolan
	Alenia Aeronautica S. p. A.		Laboratory of Fluid Mechanics and Energy
	EADS Deutschland GmbH		Mecel AB
	ZF-Luftfahrttechnik GmbH		FeONIC plc
	TACT Technology Ltd		Paragon Ltd.
	CEDRAT Technologies S. A.		University of Salford

Summary description of project objectives

MESEMA, a technology oriented research project, builded upon the success of previous EU projects with devotion to accomplish the objectives of the aeronautics priority through designing, producing and testing “innovative transducer systems based on active materials“. Four fixed and rotary-wing aircraft companies accompanied by SMEs and university research institutes participated in - and could benefit from - the developments of primarily magnetoelastic transducers for high-torque actuation, vibration and noise reduction, electrical energy generation and structural health monitoring. Structural dynamics, energy conversion in active materials and control systems represented the scientific fundamentals of the project. The scientific and technological objectives were the results of an evolution of the activities developed during the previous six years by the group which had promoted the two successful European research projects named “M.A.D.A.Vi.C.“ and “M.E.S.A.“.

The MESEMA objectives consisted mainly in the design and development of five systems, integrating vibration transducers, based on active components aimed at:

- reducing the level of disturbance noise in turbofan aircraft,
- reducing the level of disturbance noise in helicopters;
- examining the health status of aircraft structural components;
- replacing the helicopter rotor blade pitch angle actuation systems;
- transforming mechanical energy related to vibration fields within aircraft into electric one (VIBEL).

The five objectives had a common aspect in that they all required the design and development of a dedicated actuation system (including control algorithms and driving electronics) providing dynamic displacement and force fields on a host structure.

Work performed and Results achieved during the first project period

The first twelve months of the MESEMA project (01.01.2004 – 31.12.2004) were mainly characterised by the discussion and definition of requirements as well as the elaboration of specifications in different workpackages.

The main technical achievements in the first project period can be summarized as follows:

- Initial review of the existing magnetostrictive materials with reference to their performance vs. availability, reliability and cost;
- First analysis of the available technological solutions for enhanced sensing devices to be implemented/embedded in magnetostrictive actuators with reference to hysteresis compensation too;
- Issue of the mandatory requirements for the actuators needed for the two applications focused on the enhancement of the cabin comfort in helicopters and turbofan aircraft;
- Development of numerical models to be used for the design of an optimal control strategy of the interior noise in the turbofan aircraft applications;
- Dynamic experimental characterization (modal analysis) of the fuselage mock-up selected as test-article for the WP2.1;
- Review of the conceptual design solutions for the challenging problem of the helicopter pitch blade control and development of simulation aimed to a final conceptual solution;
- A preliminary analysis of the required control hardware and software according to the collection of information on the actuation and sensing needs;
- Trade-off among the best methodologies and selection of the most promising approaches for the structural health monitoring activities;
- Analysis of the structural configuration of a typical commercial aircraft and selection of structural critical components requiring Non Destructive Damage Identification system as required by “Damage Tolerance” safety issues;
- Design of the Health Monitoring system based on PC based external acquisition board driven by a dedicated code developed in NI/LABVIEW programming environment;
- Identification of the required vibration contours and data for the optimization of the VIBEL design in helicopters and aircraft;
- Production of the first prototypes of the VIBEL concept at NIRDTP and CHALMERS for laboratory tests;
- Design and development of the experimental equipment at NIRDTP, for testing the mechano-magnetic-electric transduction in Terfenol, Galfenol and other magnetoelastic materials;
- Review of conceptual design solutions of VIBEL.

Work performed and Results achieved during the second project period

The second twelve months of the MESEMA project (01.01.2005 – 31.12.2005) were mainly characterised by the design and development of first actuator prototypes and assessment of their integration on the technology demonstrator.

The main technical achievements in the second project period can be summarized as follows:

- Detailed characterisation of samples of different materials with reference to applied stress and magnetic field;
- Complete analysis of the available technological solutions for enhanced sensing devices to be implemented/embedded in magnetostrictive actuators with reference to hysteresis compensation too;
- Optimisation of the optical circuit for using Bragg sensors as strain measurement devices;
- First stand-alone hysteresis compensation module;
- Extensive literature review on smart materials and structures with reference to scientific advances, technology applications and comparison between piezo and magnetostrictive materials;
- Finite element model of the aircraft fuselage validated vs. experimental data;
- Definition of the model for control purposes
- First results on optimal placement of the control actuators and on control strategy for the turbofan technology demonstrator;
- Manufacturing of 5 proof-mass piezo-actuator prototypes and their preliminary experimental evaluation of performances for the turbofan application;
- Manufacturing of 2 inertial magnetostrictive-actuator prototypes for the turbofan application;
- First manufacturing of power amplifier devices for the turbofan application;
- Trade-off among design parameters for the development of the actuation system in the helicopter application;
- Manufacturing of first mechanical components for the actuators to be used in the helicopter application;
- Development of a complete health monitoring system with low computational needs and high reliability level in real time operation;

Work performed and Results achieved during the second project period (continued)

- Finalization of the concepts, development of an assessment scheme, assessment of different concepts and selection of one concept for further development with reference to high torque actuation;
- Assessment of the high torque actuation device with reference to the integration in the helicopter flight control system;
- Detailed design and start of the manufacture of high torque actuation hardware components;
- Study on helicopter vibrations as possible technology demonstrator for the VIBEL;
- Development of a small piezo VIBEL;
- Development of dedicated test-rigs for the experimental evaluation of VIBEL performances;
- Trade off among the key VIBEL parameters (active material, pre-stress, loading, etc.) for maximising the energy transformation;
- Production of the several different prototypes of the VIBEL concept at NIRDTP, CHALMERS, CEDRAT, EADS-CRC and TACT for laboratory tests.

Work performed and Results achieved during the last project period

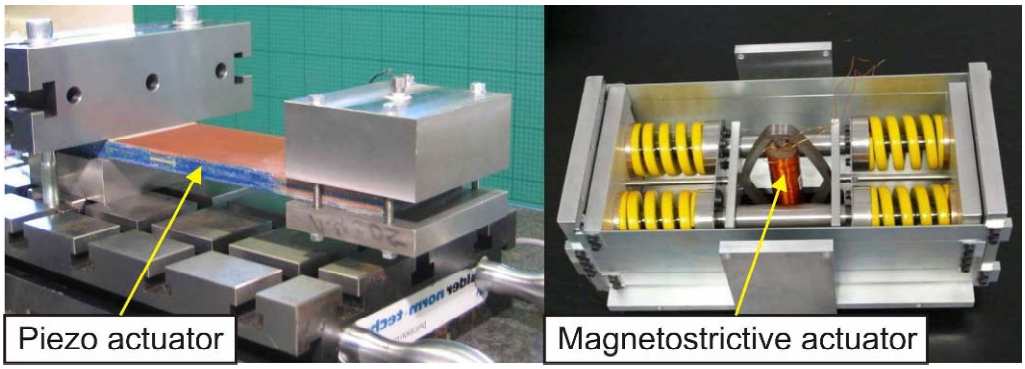
The last eighteen months of the MESEMA project (01.01.2006 – 30.06.2007) were mainly characterised by the production and experimental testing of all the devices designed during the first two project years in order to accomplish the requirements of the five selected applications. In the following a summary of the main activities is given.

- Continuous investigations of magnetoelastic materials by applying various observation methods (Optical Microscopy, Atomic Force Microscopy, Magnetic Force Microscopy, Tunneling Electron Microscopy, X-Ray diffraction, Neutron diffraction);
- Preparation and characterisation of magnetoelastic materials samples (First Actuator-Ready FeGa Samples Prepared within Consortium);
- Fiber Bragg Grating Sensors studies and development for Non-Linearity Compensation of Magneto-Elastic Actuators;
- Exploitation of Inherent Sensor Effects in Magnetostrictive Actuators;
- FPGA-Based Design and development of Stand-Alone Hysteresis Compensation Module for High-Speed Applications;
- Continuous bibliographical Research on Smart Materials and Structures;
- Design of the H_∞ controller algorithms for noise reduction;
- Final optimisation of the control actuators locations employing Genetic Algorythms and numerical structural-acoustic modelling;
- Production and delivery of a complete set of control actuators for interior noise control on turbofan aircrafts (12 actuator pairs for frame mounting and 18 single units for stringer mounting);
- Production and delivery of a complete set of hybrid amplifiers for driving the actuators developed for interior noise control on aircrafts;
- Bragg's sensor installation on control actuators for noise control in aircrafts;
- Experimental control system implementation including three dSpace rapid prototyping systems, shakers for primary disturbance field reproductions, accelerometers and microphones as control sensors as far as all the necessary conditioning electronics;
- Characterisation of the final release of the actuators developed by LPA-ZIP carried out by means of a laser vibrometer: the actuators were characterised directly in their final mounting configuration;
- New experimental characterisation of the Alenia fuselage mock-up;
- Experimental testing of the complete noise control system on the partial fuselage mock-up available in Alenia: the experiments clearly showed that the proposed noise control

system can actually reduce the overall levels of a broadband noise inside the cabin. Also the vibration levels of the structural elements of the fuselage is significantly reduced on a wide range of frequencies;

The manufacturing and assembly of the piezoelectric force generator components and its power supply for vibration reduction on helicopters;

Detailed design, simulation and production of the magnetostrictive actuator solution for vibration reduction on helicopters, and of the associated power amplifier;



Experimental testing of piezoelectric force generator for vibration reduction on helicopters including its power supply. The desired forces could be generated at the specified frequencies;

Experimental testing of magnetostrictive tunable force generation for vibration reduction on helicopters: the effectiveness of its passive behaviour as far as its the electrical tunability of the resonant frequency was checked and proved. The active force generating mode of operation was also achieved at high driving current amplitude and low mechanical preload;

Development of the Health Monitoring system based on vibration measurements: a software able to drive the acquisition board, to acquire the vibration signals and to analyse them has been developed in LABVIEW environment including the analysis part developed in MATLAB but automatically recalled within the LABVIEW Virtual Instrument;

Experimental tests and validation of the Health Monitoring approach on “small-scale” test articles in laboratory conditions also comparing statistical approach and new analysis approach based on modal parameter (mode shapes) analysis by the mean of Spatial Correlation Indexes;

Dedicated actuators development and production for the combined requirements of Noise and vibrations control and Health Monitoring topics;

Experimental characterisation of actuators produced for Health Monitoring and Interior Noise Control on turbofan aircrafts;

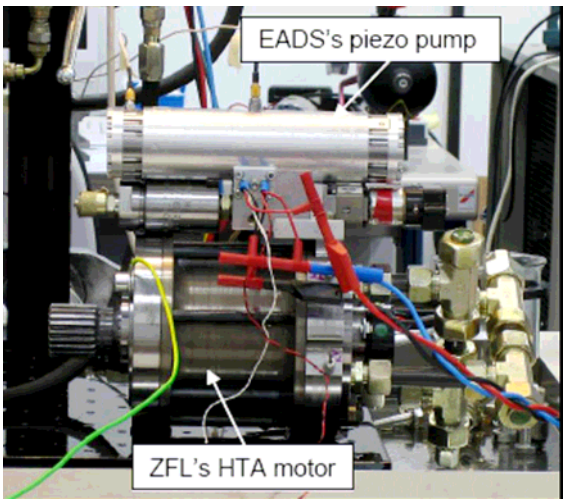
Development of a Multi-objective Genetic Algorithm (MOGA) for the selection of the optimal sensor/actuator placement in order to ensure the optimization of both acceleration (noise reduction) and health monitoring (damage index maximization);

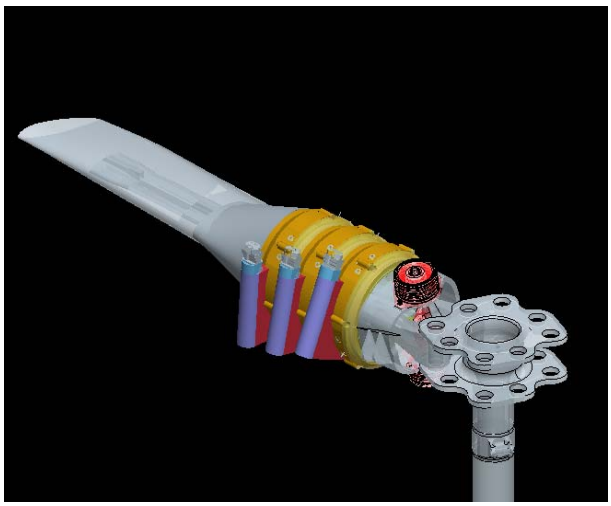
Final Health Monitoring system tests on the full scale test article (fuselage section available in Alenia);

Completion of the remaining design tasks accompanying the design of the prototype of High Torque Actuation system for rotor blade (electro-hydraulic final actuation system configuration);

Manufacturing, procurement and assembly of all the components of the HTA system including:

- Hydraulic output motor
- Piezo pump with passive valves
- Hydraulic manifold for HTA
- Terfenol pump with active valves
- Three different test setups for testing within specified operational envelope
- Power electronics for pump piston control with power-feedback capability
- Power electronics for active valves





Tests of both smart pumps produced in laboratory environment with artificially simulated loads;

Tests of the complete HTA including hydraulic motor, pump and power amplifier; the tests demonstrated a significant improvement of smart pumps as far as the potentiality of the designed actuation system;

Large VIBEL design completed and 10 Vibels built and tested for performance evaluation;

For the small Vibels complete vibration driven telemetric sensor systems were built and tested. It has been performance evaluated using recorded vibration data from a Boeing aircraft with promising results;

- Vibel adapted electrical regulator system successfully tested rendering a constant DC voltage output;
- An emergency electrical power generation system for aircrafts based on a combination of vortex tube oscillators and Vibels has been designed, built and wind-tunnel tested;
- Comparative testing of Terfenol and Galfenol alloys under various mechanical stress and magnetization conditions have been carried out providing design data for Vibel optimisation;
- A Generic Algorithm for optimal selection of Vibel location on an aircraft structure taking in account the vibrational energy distribution configuration has been developed.

Summary of end results achieved (as compared to original plan)

From a global point of view the project can be considered successful for what concerning all the selected applications. More than one working system have been developed and tested for each task, starting from very challenging specifications; it is possible to state, at the end of the project, that the specifications have been accomplished for all the applications, and new solutions to the challenging demands of the industrial partners have been provided, in most cases in the form of prototipal working systems that could be ready for industrial implementation after further engineering work that will be carried out by the end user.
Following a short summary of the main results achieved is reported on a WP basis:

- WP1 has advanced knowledge of magnetoelastic materials, produced samples for consortium, developed sensors and control modules as well as reviewed parallel research activities found in the literature.
- Within WP2.1 (Active Noise Control for turbofan aircrafts) innovative results were achieved both in terms of devices and concepts:

  Innovative devices:
  - Magnetostrictive Auxiliary Mass Damper with Bragg sensor
  - Light Hybrid Amplifier

  Innovative concepts
  - Identification procedure for dynamic model of flexible structures
  - Optimization procedure for actuator location
  - Control algorithm for noise and vibration control

  The experiments clearly showed that the proposed noise control system can actually reduce the overall levels of a broadband noise inside the cabin (-4dB(A) achieved on the overall Sound Pressure Level counteracting the primary disturb field). Also the vibration levels of the structural elements of the fuselage is significantly reduced on a wide range of frequencies.
- Within WP2.2 (Noise and Vibrations control on helicopters) project targets were accomplished by developing a piezo force generator system which can be considered ready for the industrial implementation. Tuneable vibration absorbing was demonstrated with the magnetostrictive force generator. Active mode of magnetostrictive FG demonstrated experimentally (proof of concept); achieving high forces will demand further experiments / optimization. Semi active mode is very interesting since it would permit to reduce vibration levels with very low electric power
- Within WP3 (Health Monitoring) an innovative system for analyzing structural damages was developed in LABVIEW/MATLAB environment and tested implementing different data analysis algorithm. Furthermore an innovative optimization procedure for actuators positioning was studied and numerically implemented.

  The experiments clearly showed that the proposed HM system can actually identify and localise damages on metallic and composite aeronautical structural components, employing data acquired by many types of vibration sensors.

- Research in WP4 (High Torque Actuation) lead to a working prototype of a demonstrator actuator which was tested towards the initial requirements. The power output of hydraulic power generators using smart materials (smart pumps involving piezoelectric or magnetoelastic materials) was significantly improved. The improvement was shown by bench tests with working prototypes. The working frequency of smart pumps in high-power application with sufficient pumping efficiency could be improved up to 2,1 kHz. A novel power electronics circuit capable of driving capacitors and coils with good efficicency due to power feedack capability has been built and tested.
- Within WP5 the magneto-elastic inverse transduction process of the Vibel has been extensively studied, both theoretically and experimentally and is now well understood. A total of 10 Terfenol and Galfenol Vibels of this basic deign have been built. Extensive testing of the Vibels has been performed and test rigs showing transduction efficiencies between 25 – 50 %. An air flow driven emergency electrical generator based on a combination of Vibels and vortex oscillation tubes has been designed, built and wind tunnel tested.

Methodologies and approaches employed

The MESEMA Project has been characterised by a particularly high level of multidisciplinary approaches aimed at satisfying the challenging requirements of the five selected applications/scenarios suggested by the industrial partners involved.
As a consequence the achieved results have been obtained by a combination of methodologies and approaches belonging to many fields of the engineering practice/research like numerical simulations, mechanical engineering, electronics and control, hydraulics, "smart structures", structural dynamics, elettromagnetism.
Following a short list of the main methodologies and approaches employed in each technical work package is reported; many of those have been invented/developed for the scopes of the MESEMA project.

<u>WP1 – Material research and technology review</u>

1. Analysis of structural and magnetic domains at surfaces of samples by applying various observation methods
   - Optical Microscopy
   - Atomic Force Microscopy
   - Magnetic Force Microscopy
   - Tunneling Electron Microscopy
   - X-Ray diffraction
   - Neutron diffraction
2. Samples produced via various methods
   - Amorphous wires, melt-spun ribbons and rapid and slow quenched ingots
   - First time ever production of thin-plate Fe-(Ga,Al) bulk samples
   - FeGa bars cast for implementation in T2.1 actuators
3. Fiber Bragg Grating Sensors have been employed for Non-Linearity Compensation of Magneto-Elastic Actuators
4. FPGA implementation of a Hysteresis Compensation Module for High-Speed Applications

<u>WP2.1 – Noise and vibration control on turbofan aircraft</u>

Within WP2.1 an Active Structural Acoustic Control strategy has been implemented, and several innovative strategies/methodologies have been developed. Following is a list of them:

- active structural acoustic control approach
- magnetostrictive actuators placed on structural members
- integration of optical sensors for enhancing actuator performance and controllability
- model-based structural feedback control (optimal/robust control strategy)
- optimization of actuators and sensors location based on genetic algorithms.

<u>WP2.2 – Noise and vibration control on helicopters</u>

Within WP2.2 the target of controlling vibrations levels on helicopters was achieved thanks to the development of "Active Dynamic Vibrations Absorbers". Following a list of the main approaches/methodologies is reported.

- Active Dynamic Vibrations Absorbers based on the employ of piezoelectric or magnetostrictive active components;
- Magnetostrictive materials based ADVA based on a displacement amplification design (“active pendulum”);
- Electrical tunability assessment of the Magnetostrictive device has been experimentally demonstrated;

WP3 – Health monitoring

Within WP3 an innovative approach for detecting structural damages on aeronautical components has been developed thanks to the integration of methodologies belonging to the structural dynamics and signal analysis fields:

- The approach followed focused its attention on the frequency response functions (FRFs) measurements, first of the undamaged structure and then of the damaged one.
- The implemented technique is based on the comparison between only the amplitudes of the FRFs of the healthy structure, which are assumed as a baseline, and those of the FRFs acquired after the damage has occurred.
- The study for optimising actuators and sensors locations is based on genetic algoritms.

WP4 – High Torque Actuation

WP4 represented probably the most challenging application of the MESEMA Project due to the very demanding goals in terms of requirements regarding force levels, actuation velocity, power, weight, reliability as well as integrations aspects. The final demonstrator represented a big step forward as compared to state-of-the-art devices by implementing many methodologies/devices:

- Two “smart” pumps: one piezo pump with passive valves and one magnetostrictive pump with active valves;
- Hydraulic motor optimized for coupling with the pumps;
- Power electronics for pump piston control with power-feedback capability;
- Power electronics for active valves;
- Optimisation of the passive valve pump control cycle by fluid dynamic simulation;
- Innovative integration approach of the HTA within the helicopter rotor for blade pitch angle control, taking in account demanding safety issues.

WP5 - Vibrational electrical energy (VIBEL)

Within WP5 the most innovative application for magnetoelastic devices was investigated attempting to develop approaches and design methodologies in order to optimize the conversion of mechanical energy into electric one. Following is a list of the main tools employed/developed.

- 10 Vibels characterised by different dimensions and designs were built and tested for performance evaluation;
- complete vibration driven telemetric sensor systems were built and tested for aeronautical employ;

- Vibel adapted electrical regulator system successfully tested rendering a constant DC voltage output;
- Vibel was implemented into an emergency electrical generation systems for small aircrafts based on the employ of tubes in aerodynamic flow vibrating for the “vortex shedding” occurrence.
- A Genetic Algorithms approach for optimal selection of Vibel location on an aircraft was developed.

Achievements with regard to the state of the art

The 42 months of research activities carried on within the MESEMA Consortium brought to a well recognizable step forward in the knowledge of potentialities of megnetoelastic materials in general sense and, mostly, in all the aspects related to their applications respect to the five “scenarios” selected as technological challenges of the research project. For each application a significant improvement to the actual state-of-the-art was achieved, developing innovative systems or concepts/approaches in a wide number of disciplines. In previous paragraph a summary of the results as far as of the innovations was presented; here only a short description of the step beyond the state-of-the-art respect to the five main applications will be reported.

WP1 – Material research and technology review

WP1 has advanced relevantly the knowledge of magnetoelastic materials behaviour, produced samples for consortium, developed sensors and control modules as well as reviewed parallel research activities found in the literature.

WP2.1 – Noise and vibration control on turbofan aircraft

In WP2.1 the experiments clearly showed that the proposed noise control system can actually reduce the overall levels of a broadband noise inside the cabin. The system developed was able to reduce the overall interior Sound Pressure Level in a partial fuselage section of about 4dB(A) and it was clear that performances could have been enhanced significantly spending more effort on positioning optimization of control actuators and increasing their number up to 30 functioning units as required from the numerical simulations (within the experimental set-up only 20 control point were operative). Also the vibration levels of the structural elements of the fuselage is significantly reduced on a wide range of frequencies. At the moment this represents a rare example of working NVC system based on ASAC approach and it has been developed on the basis of several innovative original approaches (including control algorithms) that permitted to achieve the results. Also the low actuators and amplifiers weights represent a step forward if compared to systems based on loudspeakers or other actuators types.

WP2.2 – Noise and vibration control on helicopters

As for the reduction of vibration levels on helicopters, the requirements were completely met by the piezoelectric active dynamic vibration absorber. The system meets the initial objective of substituting today's serial passive absorbers and thereby represents a significant product innovation. Furthermore, the semi-active mode is very interesting with a view to reducing vibration with very low electric power, and tunable vibration absorbing was demonstrated with the magnetostrictive force generator.

WP3 – Health monitoring

Much of Structural Health Monitoring (SHM) research is motivated by the fact that damage-tolerant and fail-safe design of aircraft, aerospace and civil structures requires a substantial amount of inspection and defects-monitoring at regular intervals. More specifically, it would be highly beneficial to have an SHM system characterized by low computational effort, high reliability, and with the ability to analyze the acquired data in near-real time. Such a system could identify a “perturbed” area of the structure, provide information about its presence and

location, and suggest mitigation strategies to manage the risk. Within WP3 a system able to interrogate the monitored structure and analyse the response data by the mean of statistical and/or deterministic original approaches has been developed and tested. The developed systems/algorithms can be potentially implemented for “in-board” use also thanks to the modern electronics technologies (FPGA). Such a system is at the moment in line with state-of-the-art prototypes trying to fulfill the modern needs for aircrafts components real-time health monitoring.

WP4 – High Torque Actuation

Within WP4 several improvement to then state-of-the-art actuation systems for helicopters rotor blades have been achieved. The power output of hydraulic power generators using smart materials (smart pumps involving piezoelectric or magnetoelastic materials) has been significantly improved. The improvement was shown by bench tests with working prototypes. The improvement over the known published research results is factor 2 at hydraulic output power in Watt. The working frequency of smart pumps in high-power application with sufficient pumping efficiency could be improved up to 2,1 kHz. This achievement was possible by a careful analysis of the high-frequency dynamics of the hydraulic control process (dynamics of hydraulic pressures and valve movements) and design and test of several different valve designs with choice of the design with best performance. A novel power electronics circuit capable of driving capacitors and coils with good efficicency due to power feedack capability has been built and tested.

WP5 - Vibrational electrical energy (VIBEL)

The concept of electrical energy production converting available and useless vibrational power is, by himself a step beyond in the search of small/medium energy sources distributed on aircrafts in particular and in industry/transportation field in general. Vibel concept demonstrated its effectiveness (in example the feasibility for wireless sensor applications was proven) and a transduction efficiencies between 25 – 50 % was calculated/proven. The air flow driven emergency electrical generator based on a combination of Vibels and vortex oscillation tubes represent a unique solution to the needs of these devices on small aircrafts.

Impact on the related industry or research sector

The MESEMA Consortium include the main European experts in the field of magnetoelastic materials study and application. The whole project represented a step forward in the basic knowledge of magnetoelasticity, as far as in the detailed analysis of the available materials provided by more and more producers. The database of measurement and analysis of materials properties represent by itself an impulse to this research sector permitting to explore always new application in order to exploit materials potentialities (one of the partner of the consortium – Feonic – is already a leader in the field of large scale distribution of devices based on magnetoelastic materials). Several devices/innovations developed for accomplishing the requirements in the five applications represent by themselves independent products that could be exploited (an example are the hysteresis compensation modules developed for WP2 needs, the hybrid amplifiers designed for the actuators, the identification algorithms developed for noise active control or the structural health monitoring system).
Obviously the main success of the project can be assessed by the statement of the industrial partners concerning the application they supported; following a list of these statement for the main applications are collected.

WP2.1 – Noise and vibration control on turbofan aircraft

The end-user Alenia considers the obtained results in terms of noise reduction inside the cabin worth of further investments with the aim of improving the performance for an actual exploitation of the system.

WP2.2 – Noise and vibration control on helicopters

“System is fully ready for in-flight demonstration on EC135/EC145 with technology readiness level TRL 6 (Prototype demonstration in relevant environment). System meets initial objective to substitute today's serial passive absorbers representing a significant product innovation. Technology developed is considered as ideal candidate for further noise & vibration control applications on helicopters (beyond cabin floor vibrations).” – EUROCOPTER

WP4 – High Torque Actuation

“Extremely promising piezo-electro-hydraulic actuation technology as outcome. Application in blade root control in hybrid configuration is feasible. Further promising applications in aerospace identified (e.g. piezo-electro-hydraulic helicopter rotor brake, flight control actuation).” – EUROCOPTER

WP5 - Vibrational electrical energy (VIBEL)

“Feasibility for wireless sensor applications proven. Technology meets demands of wireless applications in aerospace. High power applications represent pioneering research. Several potential applications in aerospace identified (e.g. rotating system usage monitoring, structural health monitoring systems). New application ideas developed (e.g. emergency power unit). Further research on high power capability recommended.” - EUROCOPTER