

Riferimento a linee guida	FORM N: 2 PROGRAM EVALUATION FORM
3	Nome programma / Program name Electrical Machines
3	Responsabile programma / Program responsible Augusto Morini
3	Obiettivi specifici del programma / Specific objectives of the program Development of methodologies for the analysis of electromagnetic devices by means of finite-element methods as well as by means of calculation codes self-developed by the research group. Development of automated procedures for the optimisation of the performances of electromagnetic devices.. Modelling and design optimisation of special electrical machines by means of the above-mentioned methodologies and procedures.
3	Progetti in corso / Projects Project 1 Development of calculation codes for the analysis of electromagnetic devices References: [1], [2], [3], [11] The project is part of an activity mainly financed in 2001 by the two-year research program “Methodologies for the simplified analysis of electromagnetic structures for the design of electrical machines” (Ateneo ex 60%, 2000-2001). The FEM commercial codes are generally considered as the standard tool to perform electromagnetic analyses of even complicated configurations, in particular in presence of high saturation. Anyway, often the analysis may be turned into the 2D study of cross sections; for this kind of analyses it may be advantageous to have alternative tools or to use the FEM codes with a simplified approach. The aim of the project has been therefore to provide the research group with alternative tools for the analysis of 2D electromagnetic structures, to be used in the design of electrical machines. Two different procedures have been implemented. The first procedure uses a calculation code (entirely self-developed by the research group) consisting of a new implementation of the “surface-current method” (SCM). It is a numerical 2D method in which the magnetic discontinuities are modeled by polygonals, subdivided into a suitable number of elements, with a suitable surface current - uniform and unknown - flowing in each element. The method can be applied to magnetic circuits of any shape, permanent magnets and with rectangular field sources with axes on any direction. By imposing the fulfillment of the field refraction law on each element, a linear set of equations is built, in which the unknown currents are related to the tangential component of the external field by means of coefficients depending only on the permeability and on the configuration geometry. In this way the global field can be calculated in any point, as sum of the contribution of the external sources and of the surface-current sources. The method has been implement into a PC code with the following general characteristics: - accuracy, converging speed and calculation times comparable with the ones of a commercial FEM code; - friendly interface; - reduced operator involvement and high flexibility in pre- e post-processing phases, with easy data import and export. In particular, the code includes: - an automated procedure for the refinement of the distribution of the surface elements, on the basis of suitable error indexes; - the possibility to take into account the presence of non-linear magnetic materials by means of suitable algorithms; - the integration with procedures to optimize the performances of the electromagnetic device under analysis.. The code has been used to analyze several electromagnetic devices (magnetic levitators, step motors, brushless linear motors, switched reluctance motors) and has been validated by comparing the results with the ones given by a commercial FEM code. The second procedure is called “method of the uniform magnetically anisotropic region”; it can be applied to 2D magnetically linear configurations and used to reproduce the influence of slotting on the field distribution inside electrical machines. It consists in the replacement of the slotted zone by means of a homogeneous region in which the permeability related to the field lines parallel to the slot axis is

different with respect to the one related to the perpendicular lines. By implementing the uniform region into a FEM code instead of the slotted one, the solution can be obtained in a very simple way, with reduced operator involvement and reduced calculation times.

After the method theoretical definition, a comparison has been performed, by using the same FEM code both with the real configuration and with the simplified one, with reference to both linear and rotating machines with non saturated magnetic circuit. The congruence has been verified, in terms of integral quantities (flux, mean values of forces and torques) as well as in terms of means value of the distribution of local quantities (air-gap flux density).

The method can be used also in case of relatively complicated geometries (such as semi-closed slots) by modeling the slot region by means of more than one layer. In this way parametric analyses may be performed, by varying the tooth geometry..

The method may be suitably utilized in the preliminary design of electromagnetic devices.

The procedures are described in four memories, two on the international review "COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering" and one on the "IEEE Transactions on Magnetics"; the fourth paper has been awarded by the "Ansaldo Ricerche Prize" at the "4th International Symposium on Advanced Electromechanical Motion Systems".

Project 2

Performance analysis of low-rate single-phase alternators

References: [5], [7], [8]

The project has been financed in 2001 by the two-year program "Electromagnetic analysis and design optimization of low-power single-phase synchronous generators through numerical codes", part of the national research program PRIN 1999 "Electromagnetic analysis, modeling and design optimization of low-power synchronous generators" (National scientific coordinator: A.Morini; in collaboration with Politecnico di Milano, Università di Palermo, Università di Trieste).

The aim of the project has been to develop a methodology for the modeling of low-power single-phase synchronous generators (< 10 kVA), because of their importance in the medium-small Italian electromechanical industry. The methodology combines numerical and analytical methods and is based on the definition of a circuit model allowing the analysis of the machine operation under steady-state and transient running, even with high saturation and consequent coupling effects between dq axes.

The developed mathematical model is based on the calculation of the analytical expressions of the machine self and mutual inductances, obtained by interpolating the numerical data of a sequence of FEM non-linear magnetostatic analyses (with suitable equivalent distribution of currents as field source). Then the instantaneous values of the output electrical quantities have been found by integrating the non-linear differential equations describing the electrical behavior of the alternator; such integration has been performed by using self-developed routines, instead of a commercial simulation language.

The results have been validated by a series of tests, performed on a commercial alternator. The characteristics of the machine have been obtained by means of the measurement of its electromagnetic quantities at the terminals in different running operations (no-load, short-circuit and rated conditions). Three prototypes have been also investigated in collaboration with an Italian manufacturer and a series of test has been performed at the Department of Electrical Engineering, with particular reference on the direct measurement of the winding inductances.

The last phase of the project has been related to the definition of a methodology for the parametric analysis and the electromagnetic optimization of the machine design. The described simulation procedure has been therefore applied to analyze the influence of the design parameters (geometry of the magnetic circuit, value of the capacitance, number and position of the damping bars) on the machine performances, the parameter variations being guided by a minimization algorithm of a suitable cost function.

The results are described in three papers, presented at important conferences of the field.

Project 3

Electromagnetic design of linear motors for industrial automation applications

References: [9], [10]

The project is part of an activity mainly financed by the three-year research program "Electromagnetic analysis and design optimization of linear electric motors for industrial applications" (Ateneo ex 60% 2002-2004). In the frame of the same activity, two research contracts with an electromechanical manufacturer have been drawn up.

The aim of the project has been to improve the design of linear electric motors to be used in high-dynamics drives in applications such as robotics and machine tools.

The research has been focused on the analysis of iron-less and iron-core configurations of permanent magnet linear brushless motors; for each configuration the activity has been the following:

- preliminary design of the motor by means of approximated analytical formulations, in order to get a preliminary estimation of its performances (weight, mean force, efficiency, power factor);
- verification and refinement of the design by means of both FEM commercial codes and self-developed calculation programs;
- parametric analysis with particular reference to the influence of the motor geometry on the performances;
- implementation of an optimization procedure with consequent detailed definition of the geometrical, electrical, thermal and mechanical design of the motor.

The iron-less linear brushless motors are quite interesting for their dynamic performances and high efficiency, but they require an accurate definition of the electromagnetic design, because of the stringent requirements on positioning precision and response quickness.

The automated optimization procedure minimizes a suitable objective function, sum of two terms: the first is the weighted sum of the normalized quantities related to the performances to be optimized and the second takes into account the possible infringement of geometrical and electromagnetic constraints. In particular, the aim is to optimize the motor constant (ratio between the mean thrust force and the square root of the winding joule losses) and the electrical time constant. The obtained results show a considerable performance improvement with respect to the starting reference configuration, mainly in terms of time constant (about 20 per cent reduction).

The iron-core linear brushless motors are quite interesting for their high force density and positioning precision. The requirements in their design include the reduction of weight and sizes of the mover, the reduction of thermal stresses and the force ripple, the limitation of the construction costs; such aspects are difficult to combine because they need conflicting design choices. In order to cope with these problems, a transverse-flux iron-core motor has been proposed; its main advantages are:

- the possibility to use high polar pitches without increasing excessively the mover weight;
- the winding construction and assembling are relatively simple;
- the magnetic structure can be modular;
- the reduction of the detent force can be obtained by shifting the permanent magnets of the sides of the track.

The optimization procedure has been performed with particular reference to the maximization of the specific thrust (mean value / mover weight) and to the minimization of its harmonic content. Starting from a reference configuration, the sizes of both the ferromagnetic cores and the magnets have been modified and an optimal configuration has been found, with the following characteristics:

- specific thrust higher than the one of commercial motors;
- reduction of the detent force by means of suitable combination of the core and magnet sizes;
- reduction of the normal force and of its harmonic content.

Some results are described in two papers, presented at the main conference in the field of linear motors.

Project 4

Development of in-wheel electric motors for rubber-tyred urban transport systems

References: [4], [6], [12], [13], [14], [15], [16], [17]

The project has been financed in 2003 and 2004 by the two-year program "Development of the electrical propulsion system in urban rubber-tyred transport systems in function of the type of supply", part of the national research program PRIN 2002 "Use of new technologies for air pollutionless public city transportation systems based on electrical drives" (National scientific coordinator: E.Pagano; in collaboration with Politecnico di Milano, Università di Cassino, Università "Federico II" di Napoli).

The aim of the project has been to analyze and compare some kinds of motors to be used for the propulsion of urban electric buses.

The eventual solutions for the motion transmission from the electric motor to the wheel have been preliminarily analyzed (traditional transmission with gear-box or direct transmission with in-wheel motor). The direct transmission has some advantages, such as the increase of efficiency and on-board room and the reduction of maintenance. The electric motor can be with inner rotor, coupled to the wheel through a shaft, or with outer rotor, inserted inside the rim: the last solution allows more room retrieve and the reduction of the moving parts, because of the fixed shaft. On the other side, the design requirements are very stringent: the weight and room constraints are fixed by the wheel and the air-gap must assure at the same time convenient mechanical allowance and good performance at low speed with high starting torque. Several kinds of motors proposed for this application have been analyzed and compared and particular attention has been focused on the permanent magnet (PM) synchronous motor, which is a good compromise as regards volume, weight, air-gap width, power factor and efficiency.

With reference to the PM in-wheel motors with outer rotor and surface magnets, the project has

	<p>considered three different magnetic configurations: radial flux motor (RFPM), axial flux motor (AFPM) and transverse flux motor (TFPM). For each configuration, a specific methodology has been developed, allowing the determination of the motor characteristics and the analysis of its steady-state and transient running; the methodologies can be used in the design of the machines and make possible their performance evaluation, with consequent comparison of the different configurations.</p> <p>As regards the preliminary design and the steady-state analysis, some calculation procedures have been defined, which apply to simplified geometrical models of the motors; in this way, the machines can be analyzed by means of FEM 2D magnetostatic codes or by self-developed 2D programs and the design can be initially formulated with enough precision and reduced calculation times (the results have been verified by means of FEM 3D simulations, with good congruence of the main electromagnetic quantities such as mean torque and linked fluxes).</p> <p>As regards the analysis in dynamical conditions, a calculation method has been developed, allowing the definition of the non-linear mathematical model of each motor. The parameter identification is performed by means of sequences of non-linear magnetostatic FEM analyses, through an alternative approach considering only two equivalent state variables; as a consequence the calculation times are greatly reduced in comparison with correspondent transient FEM analyses. The numerical integration of the voltage equations has been implemented by using self-developed routines and the obtained results has confirmed the methodology effectiveness in terms of both accuracy and calculation expenses.</p> <p>The performance comparison of the considered motors in terms of developed torque has been performed with the same PM mass and the same maximum current density: the first datum mainly affects the motor cost, the second one defines the maximum thermal load congruent with the degradation of insulation and permanent magnets. The comparison of the dependence of the torque on the supply current shows that both the RFPM the AFPM motors have a practically linear characteristic, while the torque of the TFPM motor is lower because of the effects of the saturation. The data comparison related to the weight of the active parts and to the motor width shows that the TFPM configuration may have a practically halved rotor weight, even if the width is higher (anyway, inside the wheel clearance gauge); on the contrary, the AFPM configuration is the heaviest one, even if the stator weight can be reduced by eliminating the stator core without sensible change in the torque value.</p> <p>The project has produced eight memories; the comparison between the different magnetic configurations of PM in-wheel motors has been the subject of an "invited paper" at an international conference of the field.</p>																																																															
4.b	<p>Risorse personale / Human resources</p> <table border="0"> <tr> <td>A.Morini</td> <td>Full professor</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>G.Martinelli</td> <td>Full professor</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>A.Tortella</td> <td>Research Assistant</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>L.Bolognese</td> <td>PhD student</td> <td></td> <td>XV cycle (2001)</td> <td></td> <td></td> <td></td> </tr> <tr> <td>M.Zerbetto</td> <td>PhD student</td> <td></td> <td>XVII cycle (2002-2003-2004)</td> <td></td> <td></td> <td></td> </tr> <tr> <td>G.Bettanini</td> <td>PhD student</td> <td></td> <td>XIX cycle (2004-2005)</td> <td></td> <td></td> <td></td> </tr> <tr> <td>S.Stellin</td> <td>PhD student</td> <td></td> <td>XX cycle (2005)</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td><i>2001</i></td> <td><i>2002</i></td> <td><i>2003</i></td> <td><i>2004</i></td> <td><i>2005</i></td> </tr> <tr> <td>Research staff</td> <td></td> <td>4</td> <td>4</td> <td>4</td> <td>5</td> <td>5</td> </tr> </table>	A.Morini	Full professor						G.Martinelli	Full professor						A.Tortella	Research Assistant						L.Bolognese	PhD student		XV cycle (2001)				M.Zerbetto	PhD student		XVII cycle (2002-2003-2004)				G.Bettanini	PhD student		XIX cycle (2004-2005)				S.Stellin	PhD student		XX cycle (2005)						<i>2001</i>	<i>2002</i>	<i>2003</i>	<i>2004</i>	<i>2005</i>	Research staff		4	4	4	5	5
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6	<p>Risorse materiali / Scientific equipment & laboratories</p>																																																															
6.a	<p>Laboratory of Electrical Machines</p> <p>The laboratory has been established with the aim to develop both theoretical and experimental research. The computation facilities consists of five desktops and workstations; the software licenses include 2D/3D FEM codes (Ansoft Maxwell 2D and Cedrat Flux 2D/3D) for the electromagnetic and thermal analysis of electrical machines and several simulation codes (Ansoft Simplorer, Matlab/Simulink with SimPowerSystem, PS-Cad).</p> <p>The experimental facilities consists of a testing bench with a brushless drive (P=4 kW) for torque measurement with torquemeter, automatic data acquisition system and related instrumentation.</p>																																																															

7	Rapporti con altri istituti di ricerca a livello locale, nazionale e internazionale / Collaborations with research institutions and industries						
7.a	In the frame of the national PRIN projects: Polytechnic of Milan (prof. M.Andriollo) University Federico II - Naples (prof. E.Pagano) University of Cassino (prof. C.Attaianes)						
7.b	Nuova Saccardo Motori srl Company (Project 2) Baccini srl Company (Project 3)						
9	Altre attività rilevanti per la ricerca, a livello di Programma / Other research-related activities						
	Prof. A.Morini is member of the Technical-Scientific Committee of International Conferences, such as: - "International Conference on Magnetically Levitated Systems and Linear Driver – MAGLEV" - "International Symposium on Linear Driver for Industry Applications – LDIA" - "Symposium on Power Electronics. Electrical Drives, Automation & Motion – SPEEDAM"						
11	Prodotti della ricerca / Research outcome						
11.b		2001	2002	2003	2004	2005	Total
	Journal papers	3			1	2	6
	Chapters in book		1			1	2
	Proceedings of Conferences		3	3	2	1	9
		-----	-----	-----	-----	-----	-----
		3	4	3	3	4	17
11.c	<p>Product 1 M.Andriollo, L.Bolognese, G.Martinelli, A.Morini, A.Tortella: "Electromagnetic design improvement of a switched reluctance motor by a surface current method procedure", 4th International Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION '01), Bologna, 19-20 giugno 2001, pp.327-332 (published on <i>Electromotion</i>, vol.8. n.3, luglio-settembre 2001, pp.125-132).</p> <p>Product 2 M.Andriollo, G.Baccini, G.Martinelli, A.Morini, A.Tortella: "Design optimisation of slotless linear PM motor", 4th International Symposium on Linear Drives for Industry Applications (LDIA 2003), Birmingham (Regno Unito), 8-10 settembre 2003, pp.203-206.</p> <p>Product 3 M.Andriollo, G.Martinelli, A.Morini, A.Tortella: "Application of the surface-current method to the analysis of saturated electromagnetic devices", <i>COMPEL</i>, vol.23, n.1, 2004, pp.328-347.</p> <p>Product 4 M.Andriollo, G. Bettanini, G.Martinelli, A.Morini, A.Tortella: "Performance analysis of an in-wheel vernier hybrid motor for electric propulsion", 6th International Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION 2005), Losanna (Svizzera), 27-29 settembre 2005 (pubblicato su <i>Electromotion</i>, vol.13, n.1, gennaio-marzo 2006).</p> <p>Product 5 M.Andriollo, G. Bettanini, G.Martinelli, A.Morini, S.Stellin, A.Tortella: "In-wheel permanent magnet motors for public transport application" (invited paper), 5th WSEAS Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '05), Tenerife (Isole Canarie, Spagna), 16-18 dicembre 2005 (pubblicato con il titolo "Electromagnetic Design of In-wheel Permanent Magnet Motors" su <i>WSEAS Transactions on Power Systems</i>, vol.1, n.2, febbraio 2006, pp. 303-310).</p>						

ANNEX

References

2001

- [1] M.Andriollo, G.Martinelli, A.Morini, A.Tortella: "Finite-element modelization of slotted configurations by means of magnetically anisotropic smooth cores", *COMPEL*, vol.20, n.1, 2001, pp.140-151.
- [2] M.Andriollo, L.Bolognese, G.Martinelli, A.Morini, A.Tortella: "Optimization of magnetic suspension devices by a surface-current method", 8th Conference Joint MMM-Intermag Conference, San Antonio (Stati Uniti), 7-11 gennaio 2001 (pubblicato su *IEEE Transactions on Magnetics*, vol.37, n.4, luglio 2001, pp.2877-2880).
- [3] M.Andriollo, L.Bolognese, G.Martinelli, A.Morini, A.Tortella: "Electromagnetic design improvement of a switched reluctance motor by a surface current method procedure", 4th International Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION '01), Bologna, 19-20 giugno 2001, pp.327-332 (pubblicato su *Electromotion*, vol.8. n.3, luglio-settembre 2001, pp.125-132).

2002

- [4] M.Andriollo, G.Del Torchio, G.Martinelli, A.Morini, A.Tortella: "Innovative technologies for the public transportation in the Urban Mobility Plan of Padova", Urban Transport 2002, Siviglia (Spagna), 13-15 marzo 2002 (pubblicato su *Urban Transport VIII - Urban Transport and the Environment in the 21st Century*, WIT Press, Southampton, 2002, pp.75-88).
- [5] M.Andriollo, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "Electromagnetic transient simulation of single-phase synchronous generators by a non-linear dq model", Symposium on Power Electronics, Electrical Drives, Automation & Motion (SPEEDAM 2002), Ravello, 11-14 giugno 2002, pp.B3 25-34.
- [6] G.Martinelli, A.Morini, A.Tortella: "New technologies in urban transport systems", Symposium on Power Electronics, Electrical Drives, Automation & Motion (SPEEDAM 2002), Ravello, 11-14 giugno 2002.
- [7] M.Andriollo, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "A non-linear d-q model for the analysis of low power single-phase synchronous generators", 15th International Conference on Electrical Machines (ICEM 2002), Bruges, (Belgio), 25-28 agosto 2002, paper 335.

2003

- [8] M.Andriollo, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "Performance improvement of low-rate single-phase alternators", IEEE International Electric Machines and Drives Conference (IEEE IEMDC'03), Madison (USA), 1-4 giugno 2003, vol.2, pp. 1137-1143.
- [9] M.Andriollo, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "Performance evaluation of a TF linear PM motor", 4th International Symposium on Linear Drives for Industry Applications (LDIA 2003), Birmingham (Regno Unito), 8-10 settembre 2003, pp.41-44.
- [10] M.Andriollo, G.Baccini, G.Martinelli, A.Morini, A.Tortella: "Design optimisation of slotless linear PM motor", 4th International Symposium on Linear Drives for Industry Applications (LDIA 2003), Birmingham (Regno Unito), 8-10 settembre 2003, pp.203-206.

2004

- [11] M.Andriollo, G.Martinelli, A.Morini, A.Tortella: "Application of the surface-current method to the analysis of saturated electromagnetic devices", *COMPEL*, vol.23, n.1, 2004, pp.328-347.
- [12] M.Andriollo, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "A Transverse flux wheel hub motor for electric buses", Symposium on Power Electronics, Electrical Drives, Automation & Motion (SPEEDAM 2004), Capri, 16-18 giugno 2004, pp.84-90.
- [13] M.Andriollo, M.Forzan, G.Martinelli, A.Morini, A.Tortella, M.Zerbetto: "Performance analysis of a transverse flux wheel motor by a non-linear mathematical model", 16th International Conference on Electrical Machines (ICEM 2004), Cracovia, (Polonia), 5-8 settembre 2004, paper 406.

2005

- [14] G.Martinelli, A.Morini, A.Tortella: "Innovative technologies for public electric transport systems", Urban Transport 2005, Algarve (Portogallo), 12-14 aprile 2005 (pubblicato su *Urban Transport XI - Urban Transport and the Environment in the 21st Century*, WIT Press, Southampton, 2005, vol.1, pp.569-579).
- [15] M.Andriollo, G. Bettanini, G.Martinelli, A.Morini, A.Tortella: "Design and analysis of a SPM in-wheel motor for the propulsion of electric buses", 6th International Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION 2005), Losanna (Svizzera), 27-29 settembre 2005.
- [16] M.Andriollo, G. Bettanini, G.Martinelli, A.Morini, A.Tortella: "Performance analysis of an in-wheel vernier hybrid motor for electric propulsion", 6th International Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION 2005), Losanna (Svizzera), 27-29 settembre 2005 (pubblicato su *Electromotion*, vol.13, n.1, gennaio-marzo 2006).

- [17] M.Andriollo, G. Bettanini, G.Martinelli, A.Morini, S.Stellin, A.Tortella: "In-wheel permanent magnet motors for public transport application" (invited paper), 5th WSEAS Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '05), Tenerife (Isole Canarie, Spagna), 16-18 dicembre 2005 (pubblicato con il titolo "Electromagnetic Design of In-wheel Permanent Magnet Motors" su *WSEAS Transactions on Power Systems*, vol.1, n.2, febbraio 2006, pp. 303-310).

Financial resources 2001-2005

Research projects

PRIN 2002 (30800 € – 2 years)

“Sviluppo di sistemi di propulsione elettrica per sistemi di trasporto urbani su gomma a guida vincolata in funzione delle tipologie di alimentazione”

PRIN 2005 (56845 € – 2 years)

“Criteri di progetto e ottimizzazione di generatori elettrici per la produzione di energia per via eolica”

Ateneo ex 60% (5165 € – 2001)

“Metodologie per l'analisi semplificata di strutture elettromagnetiche lineari al fine della progettazione di macchine elettriche”

Ateneo ex 60% (15805 € - 2002-2003-2004)

“Analisi elettromagnetica e ottimizzazione del progetto di motori elettrici lineari per applicazioni industriali”

Ateneo ex 60% (5925 € - 2005)

“Analisi e confronto delle prestazioni di generatori elettrici per la produzione di energia per via eolica”

Research contracts

2001 - Baccini s.r.l. (18590 €– 6 months)

“Analisi elettromagnetica e caratterizzazione di motori lineari MP ironless”

2002 - Baccini s.r.l (18000 € – 6 months)

“Analisi elettromagnetica ai fini della progettazione di motori lineari ironcore a magneti permanenti”