

**Modulo 2:**

Riferimento a linee guida	<b>FORM N. 4: PROGRAM EVALUATION FORM</b>
3	<b>Program Title</b> Nome programma:
	<b>ELECTROHEAT AND ELECTROMAGNETIC BIOMEDICAL APPLICATIONS</b>
3	<b>Coordinator</b> Responsabile programma
	Prof. Sergio LUPI
3	<b>Program Tasks</b> Obiettivi specifici del programma
	<p>At the Department of Electrical Engineering of Padua University (Italy) a well-established tradition exists of research in the field of Electroheat, developed for a long time, till his death, under the guidance of the emeritus prof. C.Di Pieri, price-winner of the UIE (International Union for Electroheat) in 1980, and continued till today by his pupil prof. S.Lupi</p> <p>A great impulse to the research was given in 1969, when the Electroheat Laboratory was first established; its activity is evidenced today by more than 250 published papers [37]. The research activity is generally devoted to the industrial applications of electroheat technologies but, in particular, on problems related to direct resistance heating, medium- and high-frequency induction heating and dielectric heating.</p> <p>A close cooperation exists with manufacturers and users of electroheating equipment, in the frame of research contracts on specific research topics.</p> <p>In the last five years a new field of research in the frame of the laboratory activities has been started by prof. F. Dughiero. This new field deals with the biomedical applications of heating by electromagnetic sources, in particular the hyperthermia treatments of cancer tissues.</p> <p>Official international cooperation agreements and personal contact link up the laboratory with the Institute ETP for Electrothermal Processes of Hanover University (Germany), the Electrotechnical University ETU of St. Petersburg (Russia), the State Technical University of Novosibirsk (Russia) and the Engineering Faculty of UNESP - State University of Saõ Paolo (Brasil).</p> <p>Among the international activities, mention must be made of the organisation of the International Seminars IHS-98 - "Induction Heating", held in 1998, HIS-01 - "Heating by Internal Sources - Induction, Dielectric, Conduction", held in Padova in September 2001 and the HES-04 – “Heating by Electromagnetic Sources”, held in Padova on June 2004.</p> <p>The activities of LEP can be divided into different categories: teaching, fundamental research and application research in co-operation with industry.</p>
3	<b>Running Projects</b> Progetti in corso

The main research projects developed and started in the years 2001-2005 have been focused on the following topics:

1. Transverse flux induction heating of thin metal strips
2. Optimisation techniques applied to the design of induction heating inductors
3. Re-heating of aluminium alloys thixocasting billets
4. Development of single or double-frequency longitudinal levitators
5. Resistance heating of curvilinear workpieces
6. Single- or double-frequency induction hardening of gears
7. Shielding induction heating systems for reduction of EM field human exposure
8. Innovative high efficiency technologies for induction heating of aluminium strips and billets.
9. Biomedical applications of heating by electromagnetic sources

Moreover, some research carried out in the frame of research contracts between the Department and commercial Companies, have produced important outcomes, with the realisation of new industrial installations:

10. Important projects in the frame of contracts with industrial partners

The research activity is documented by the publications listed in the **APPENDIX 1**.

Before describing the above projects, we would like draw the attention of the reader that the institutional economical support to the projects from 1 to 7 has been the funds so called “Ricerca scientifica fondi quota ex 60%”, for a total amount in the five years of 21.851 € and those of “PRIN 2000 (20/12/2000 – 20/12/2002)” entitled “Advanced tools for optimisation in electromagnetic device design” for an amount of 28.405 €. **This means total institutional funds of 50.256 €.**

The only alternative source for funding the research projects was the commercial activity in the frame of **contracts with the industry for a total amount in the five years of 320.412 €.**

### **Project 1: Transverse flux (TF) heating of thin metal strips**

This research was started in 1998 in the frame of a two years European Craft Project (N.JOE3-CT98-7203) developed in co-operation with the University of Hannover, two Italian industrial partners and two German industrial users. This project was aimed to the development of design procedures for the TF inductors and the realisation of a laboratory prototype (100 kW, 2 kHz, 1-10 m/min) installed at the Laboratory of Electroheat of the Department. The research was focused to the heating of precious metal and low resistivity metal strips.

After the end of this project the research in this field was continued in the following directions: 1) the optimisation of the design of the inductors; 2) the improvement of the numerical models used for the analysis of the heating transients in the strips, taking into account the variations of the electrical and thermal characteristics of the material from point to point with temperature and the velocity of movement of the strip; 3) the analysis of the TF heating of ferromagnetic workpieces.

This research was also carried out in co-operation in the frame of a contract with an Italian producer of induction heating installations; the results obtained were used for the

design of a hardening installation 600 kW, 27 m/min presently in operation in China.

### **Project 2: Optimisation techniques applied to the design of induction heating inductors**

The optimal design of induction heating systems requires, in most cases, the achievement of several objectives to be fulfilled at a time and described by objective functions numerically ill-conditioned.

The corresponding multi-objective problem can be solved in the following different ways:

- Scalarisation of the objectives, based on fuzzy logic, and by means of different weights for each
- A separate research of the optimum for each objective function and choice of the best compromise
- Optimisation by means of Pareto criteria

The only way, which permits to overcome a personal component in the choice, is the third one. In fact the Pareto criteria give in an objective way a set of non-dominated solutions in the space of the objective functions. In this field a lot of work has been done in Laboratory of Electroheat of Padova in co-operation with University of Pavia and with the aim of solving some industrial problems.

The coupling between the optimisation procedure and the FEM code is necessary in order to obtain a complete automatic design procedure. Together with the development of the procedure described in the previous statements sensitivity analysis techniques will be used in order to obtain a preliminary exploration of the cost function behaviour in such a way to reduce the number of the design variables of the problem or to analyse the influence of each variable in the objective function.

An interesting and novel application of this research is the dynamic optimisation for the design of continuous induction heating plants. In fact in these systems it is not sufficient to optimise the shape of the inductor or a electrical supply quantity (frequency, voltage, current) but is necessary to optimise the time behaviour of the temperature or specific power.

### **Project 3: Re-heating of aluminium alloys thixo-casting billets**

The casting of semi-solid aluminium alloys under pressure is an important industrial technique characterised by outstanding performances. Depending on the solid fraction percentage, the aluminium alloy shows a higher viscosity that allows the casting under pressure inside a mould without turbulent movements of the melted metal. As a consequence, the semi-solid casting allows a significant improvement of the quality of workpieces, because it reduces the inclusions of gasses and the defects that occur during quenching. Moreover, the mould can last for more operations because the process temperature is lower in comparison with a traditional aluminium casting technique. The “Thixocasting” technology starts from special billets where the aluminium alloy shows a globular structure produced by a previous electromagnetic stirring process. This special billet must be re-heated before casting.

The main technological requirement of the re-heating process is the achievement of a very uniform final temperature distribution, corresponding to the 50% solid fraction. This means final temperature values of about  $582 \pm 3$  °C in the whole billet volume for the A356 alloy.

In the last years the re-heating of 5” diameter billet was introduced, with re-heating

times of about 22 ÷ 25 minutes.

The purpose of this research was to reduce these high re-heating times and increase the process efficiency, by a special two-steps re-heating cycle which fulfils these stringent temperature requirements. It allows a significant increase of the production rates by the use of two inductors fed by two different frequency converters.

The setting-up of this new re-heating process and the corresponding induction heating installation has been the objective of a large theoretical and experimental activity.

#### **Project 4: The development of single or double-frequency longitudinal levitators**

The longitudinal electromagnetic levitators (LEL) consist of a set of longitudinal exciting conductors, parallel to the axis of a non-magnetic cylindrical levitating load, carrying large high-frequency currents. The exciting conductors are constituted by a set of copper tubes conveniently end-connected in order to obtain currents flowing in opposite directions in adjacent conductors, creating a convenient alternating electromagnetic field. The currents induced in the cylindrical load by this field, interacting with it, produces the levitation force which counteracts gravity and the Joule heating of the load.

In the frame of this project a mathematical model of LEL based on the analytical solution of Maxwell equations has been developed considering the electrical currents in the exciting conductors as “filament currents” and assuming constant material properties. This tool has been used for the design of a LEL laboratory prototype for the levitation and melting of a small aluminium samples (12 mm. diameter, 100 mm length). A series of calculations and laboratory tests has been carried out for analysing the influence of the exciting frequency and other design parameters; the experimental results have confirmed the reliability of the analytical tool.

In a second phase the mathematical model has been improved in order to take into account the simultaneous action on the inductor of different exciting frequencies. In fact it is well known that the optimal frequency for the levitation force is not the same frequency optimal for the workpiece’s heating.

With this new tool novel LEL geometrical configurations have been studied for the development of a new laboratory prototype for levitating and melting bigger aluminium billets, taking necessarily into account the characteristics of the frequency converters available at the Laboratory of Electroheat of Padova (LEP).

At the same time a FEM numerical code has been developed, able to consider the double-frequency excitation field, in order to compare the simplified calculation with “filament currents” with the results obtained for the real inductor geometry.

This project is still under development since the lack of funding has retarded the construction of the double-frequency prototype.

#### **Project 5: The resistance heating of curvilinear workpieces**

This project has been developed in the frame of the co-operation agreement between the Department and the State Technical University of Novosibirsk (Russia).

It relates to the current and the temperature distribution in curvilinear ferromagnetic workpieces (rods and tubes) heated by a.c. currents directly flowing in the conducting material.

The research has been carried out both by numerical FEM calculations and experimental tests, analysing also different technical provisions (e.g. magnetic yokes, uneven thermal insulation) for reducing the unevenness of the temperature distribution in the workpieces.

A special outcome of this activity has been the publication, in Russian, of the book “Direct Resistance Heating of Metals” edited by the Novosibirsk State Technical University, in which the new results of this research are given. [30]

### **Project 6: The single- or double-frequency induction hardening of gears**

The aim of contour hardening of gear wheels is to obtain a uniform hardened layer along the whole contour of the gear wheel.

There are mainly two different approaches in the simultaneous induction hardening of gears. Either one single frequency is used or two different frequencies are applied. The techniques of how to vary the frequency, the time and the power density have led to many different approaches over the past years. One technique in particular seems to accomplish very good results in contour hardening, namely Simultaneous Double Frequency (SDF) induction hardening.

The SDF method for contour hardening combines MF and HF powers and induces them through one inductor in the workpiece. Achieving a contour hardness pattern mainly depends on the correct heating of the surface, depending on the power densities applied for each frequency. The correct combination of power densities and heating times are the main parameters in order to achieve the desired contour hardening with such a process.

The new SDF technology makes use of the MF as the ground wave with the HF being superimposed on it. In addition to that, both the MF and HF amplitudes can be independently regulated, which enables to adjust the energy density delivered to the part, forcing the eddy currents to flow more evenly along the contour of the surface.

The power densities are adjusted in such a way, that a uniform temperature of constant depth along the surface is accomplished. In order to prevent heat conduction from through heating of the teeth and creating a needed heat accumulation in the tooth root, a power density of 6 to 8 kW/cm<sup>2</sup> has to be applied. In addition to such high power densities, the heating times are very short, ranging from 0.15 to 0.8 seconds.

A new research activity was started in this field in 2004 in the occasion of the staying in our laboratory of a German student coming in Padua for the development of his final project in the frame of an Erasmus agreement with the Institute for Electrothermal Processes of the University of Hannover.

The activity presently being carried out in this field is the development of numerical FEM models for the calculation of the heating transients with the double frequency excitation. The problem is particularly complex due to the non linearity involved, the transition of the Curie point and the very short heating times.

This activity have attracted the interest of some foreign Companies working in this field and contacts are under development for drawing up a contract of co-operation.

### **Project 7: Shielding induction heating systems for reduction of EM field human exposure**

Induction heating installations are often high rated power plants, with inductors supplied with relatively low voltage but sometimes very high current intensity. For this reason in the surroundings of induction heating installations high values of magnetic flux densities can be found.

In the ICNIRP guidelines the exposure limits for workers have been fixed in order to preserve the health of employees. Sometimes these limits are overcome bringing to a dangerous situation for the operators of the machine. At LEP exists a research interest in this field both from the point of view of evaluation of electromagnetic fields in the

surrounding of the installations and in the mitigation of this levels by means of appropriate shielding. Specific numerical methods have been implemented in order to predict the efficiency of the shielding for different geometries, frequency values and power of the installations. Moreover a lot of experimental tests have been done both in our laboratory and in co-operation with industry in order to evaluate the correctness of the shielding design procedure.

### **Project 8: Innovative High Efficiency Technologies for Induction Heating of Aluminium Strips and Billets**

In 2005 a national project (PRIN 2005) entitled “ Innovative High Efficiency Technologies for Induction Heating of Aluminium Strips and Billets” (“Tecnologie innovative ad alto rendimento nel riscaldamento ad induzione per trattamenti termici di billette e nastri di alluminio”) has been approved by the Italian Ministry of Education and Research (Ministero dell’Istruzione e della Ricerca).

A preliminary theoretical activity has been developed in 2005, but the main activity will be done in 2006-2007, since the official date of start of the project is January 31, 2006

The project is aimed to study innovative technologies to be applied in the metallurgical sector of non magnetic materials with the perspective of increasing the efficiency of the heating processes of aluminium and aluminium alloys up to values of 70-90%.

The processes that will be investigated are:

- a) the Transverse Flux induction Heating (TFH) of aluminium and aluminium alloys strips and sheets
- b) the induction through-heating of aluminium billets rotating in a DC magnetic field produced by super-conducting coils.

In both cases the investigation will be focused not only on the theoretical aspects of the heater design, but also on experimental tests campaign on prototypes of the heaters aimed to verify and demonstrate the potentials of these processes.

a) In particular, with reference to the TFH process, the Units of the Universities of Padua and Rome will focus the investigation on the heat treatment of aluminium-zinc 7020 strips, because of the interest for this material of the aeronautical, aerospace and automotive industries.

This part of the project can be considered as the continuation of the project n.1. In this phase ad hoc numerical Finite Elements codes will be developed for analysing not only the electromagnetic and thermal aspects (e.g. the induced currents, the volume specific power and the temperature distributions in the strip to be heated), but also the deformations due to the non uniform temperature distribution during the heating process and to the electrodynamic forces arising from the interaction of the high exciting magnetic field and the currents induced in the strip.

The developed codes will be used for a deep parametric analysis of the TFH systems and the optimisation of the design of a new inductor prototype, which will be installed at the Laboratory for Electroheat of Padua University, where a controlled speed continuous movement system for strips of different widths and a converter with output frequency 1-4 kHz, 100 kW output power are available.

A campaign of tests will be performed on this prototype by the researchers of the Units of Padua and Rome.

b) In aluminium forging plants 50 Hz induction heaters are used for through heating billets prior to hot working from ambient temperature up to about 500 °C to soften the metal before the billet is pressed in the die. These heaters are very compact and powerful and are characterised by a high production rate. The largest ones operate at magnetic field up to around 0.7 T, with power ratings exceeding 1 MW.

In the conventional induction heaters, the exciting coils are usually made with hollow water-cooled copper windings; the fundamental problem is obtaining a strong magnetic field limiting the resistive losses in the windings. Since, as previously indicated, in this application the electrical efficiency usually does not reach 50%, this means that about 50% of the input power is transformed into heat in the copper windings and is removed by the cooling water.

For improving the energy efficiency of this through heating process, an innovative induction technique has been proposed, which makes use of super-conductive windings, i.e. low losses components able to produce high intensity magnetic fields in large volumes.

The new proposed techniques makes use of a static magnetic field produced by a DC super-conductive magnet, thus obtaining the following benefits:

- The cryogenic costs are reduced having to compensate for the heat leakage to the environment only
- The DC cable structure is heavily simplified with respect to a AC one, and consequently the magnet costs are lower.

The production of the induced currents in the billet is obtained by its rotation in the magnetic field of the DC magnet by means of an induction motor. The rotation causes the flow of induced surface currents which generate a resistant torque that opposes to rotation. These currents in turn produce Joule heating in the billet, thus converting nearly all the mechanical power supplied to it into thermal power. Consequently the efficiency should approach the efficiency of the electric motor, that for large motor sizes is well above 90%.

The following problems, related to this new technique, will be investigated by the Units of the Universities of Padua and Bologna:

- the induced currents produce a reaction field that may produce transient troubles to the SC windings
- the mechanical transmission of the torque to the billet may become problematical when the metal soften
- the induced currents flow on the surface of the workpiece and consequently the induced power density is concentrated near the billet surface. This produces a non uniform temperature distribution in the billet cross section, while the hot working process requires to limit to 5-10% the maximum temperature differential in order to guarantee a long life of dies and avoid local melting and cracking during plastic deformation.

A possible solution to the last problem can be obtained through the realisation of heating transients providing suitable temperature equalisation intervals which will allow the heat conduction from the surface towards the billet axis to take place.

In order to analyse and solve the above mentioned problems and to evaluate the performance and costs of the proposed system, a large simulation activity will be done in the project, both with the developed and commercial codes for analysing the electromagnetic and thermal fields distributions and optimising the design of the DC windings.

The results of the parametric analyses and the optimisation procedures will be used for the design of a laboratory prototype with conventional DC windings, around 5 kW power, which will allow the researchers of Bologna and Padua Units to verify by tests the performances theoretically estimated and to experience the main problems which must be solved for the practical application of the process.

The total grant requested for this research was of 194.000 €; the total economical support given to the partner Universities is 109.000 €, to the Unit of the Department about 52.000 €.

### **Project 9: Biomedical applications of heating by electromagnetic sources**

The expertise acquired in field of electroheat applications and in particular in the heating by electromagnetic sources has given the opportunity to our group to apply the knowledge in a new filed of research related to the application of EM field for heating human body. Hyperthermia is a treatment which can be used alone or in combination with radiotherapy or chemotherapy for treatment of cancer. It consist in increasing the temperature of the tissue up to 45-46°C in treatment combined with RT or CT, and 60-80°C in ablation therapy i.e. in liver metastases treatment.

The research in this field is devoted to the simulation of hyperthermic treatments both in ablation therapy and in RF capacitive hyperthermia. Thermoseeds method, RF ablation, RF capacitive hyperthermia are methods which have been taken into consideration in our research. The numerical methods used are Finite Element Method and cells method: the last one is a method based on a finite formulation of field problems introduced by prof. Tonti. The aim of the simulations is a proposal of treatment planning procedure in order to predict SAR and temperature distribution before and during the hyperthermia application. This procedure starts from a CT or NMR segmentation images in order to build the patient model. In the same geometric model an appropriate mesh is associated in order to solve by numerical methods the electromagnetic and thermal problems. The main peculiarity of these models in comparison with the classical models used in induction heating or dielectric heating applications are found in the characteristics of materials (tissues) and in the presence of a diffuse and localised perfusion (capillaries and main vessels) which gives a non linear heat sink inside the tissues. The models have been used for different applications: use of thermoseeds for hepato-carcinoma and liver metastases hyperthermic treatments, RF-capacitive Hyperthermia for pelvic tumours, RF ablation therapy for treatment of liver metastases, RF- capacitive hyperthermia for brain tumours treatments. Several papers have produced and presented to different international conferences and published in international journals.

### **Project 10: Important projects in the frame of contracts with industrial partners**

Among the many research projects developed in the frame of contracts with industrial partners, we would like to mention the following which have resulted in the realisation of innovative industrial installations, described also in papers published by international journals:

- ◆ Intermediate induction heating in hot mills for flexible steel production” [8,13]
- ◆ TFH – transverse flux induction heating of non-ferrous and precious metal strips” [18]
- ◆ Innovative induction heating process line for hardening and tempering spring steel wire [31,46]

4.b	Personnel Risorse personale
	<ul style="list-style-type: none"> <li>❖ <b><u>Prof. Sergio Lupi (Full professor):</u></b> <ul style="list-style-type: none"> <li>- vice-director of the Department;</li> <li>- honorary professor of the Electrotechnical University ETU of St. Petersburg (Russia);</li> <li>- member of committee (“Collegio dei docenti”) coordinating the activities of the PhD course in Electrical Engineering;</li> <li>- coordinator of the Working Group “Education and Research” of the UIE (International Union for Electroheat);</li> <li>- member of the Technical Committee 27 “Industrial Electroheating Equipment” of IEC (International Electrotechnical Commission);</li> <li>- member of the Working Group WG09 of CENELEC TC106X;</li> <li>- member of the Technical Committee 27 “Elettrotermia” of CEI (Comitato Elettrotecnico Italiano);</li> <li>- member of the Technical Committee 106 “Human exposure to electromagnetic fields” of CEI (Comitato Elettrotecnico Italiano).</li> </ul> </li> <li>❖ <b><u>Prof. Fabrizio Dughiero (Associate professor):</u></b> <ul style="list-style-type: none"> <li>- member of the Working Group WG09 of CENELEC TC106X;</li> <li>- member of the Technical Committee 27 “Elettrotermia” of CEI (Comitato Elettrotecnico Italiano);</li> <li>- member of the Technical Committee 106 “Human exposure to electromagnetic fields” of CEI (Comitato Elettrotecnico Italiano).</li> </ul> </li> </ul> <p>From the experience done by prof. Dughiero in the frame of the Laboratory for Electroheat, a new high-tech company was born in 2004 with the aim of technology transfer in the field of Innovative Heating Technologies. This company - INOVA s.r.l. Electrical Engineering for Innovation – is a spin-off company founded by prof. Fabrizio Dughiero, which is participated by University of Padova. This company has a partnership with CEDRAT which is one of the most important companies in the world in the field of CAE software for Electrical Engineering Applications. Up to now INOVA is increasing its incoming, cooperating with small, medium and big industrial companies in different fields (steel industry, heat treatments, automotive, food and drinks, etc.). Inova has employed 5 persons with high degree of scientific ad technical skill (PhD degree).</p> <ul style="list-style-type: none"> <li>❖ <b><u>Dr. Michele Forzan</u></b> (research grant from Sept. To Dec. 2004; assistant researcher from 07/01/2004)</li> <li>❖ <b><u>Dr. Ing. Marco Bullo</u></b> (Ph Doctor, now part-time laboratory technician)</li> <li>❖ Ing. Enrico Tittone (PhD student; years 2002-2004)</li> <li>❖ Ing. Valentina D’Ambrosio (PhD student; from 2004)</li> <li>❖ Ing. Cristiano Greggio (PhD student; from 2005)</li> <li>❖ Ing. Marcello Zerbetto (collaborator in the frame of research contracts with industry; from Nov. 2005)</li> </ul>
5.b	Funds [average in the 5 years period] Risorse finanziarie [media quinquennale]
	As previously underlined, the institutional economical support to the projects from 1 to 7 has been the funds so called “Ricerca scientifica fondi quota ex 60%”, for a total amount in the five years of 21.851 €, those of “PRIN 2000 (20/12/2000 – 20/12/2002)”

	<p>entitled “Advanced tools for optimisation in electromagnetic device design” for an amount of 28.405 €. <b><u>This means total institutional funds of 50.256 €.</u></b></p> <p>The project n.8 is at its beginning, since in 2005 only preliminary analyses were developed resulting in a successful application for funding; the corresponding availability of funds and therefore the main activity started at the beginning of the year 2006. <b><u>The grant given for this research (PRIN 2005) is of about 51.000 €.</u></b></p> <p>The only alternative source for funding most of the research projects has been the commercial activity in the frame of <b><u>contracts with the industry for a total amount in the five years of 320.412 €.</u></b> (see <b><u>APPENDIX 2</u></b>)</p> <p>This means (excluding the funds from PRIN 2005) a total amount of funds of 370.668 € in five years corresponding to a mean value per year of about 74.000 €/year. Including the project n.8 the mean value per year rises to 84.300 €/year.</p> <p>In particular, the institutional funding was dedicated to the different projects as follows:</p> <ol style="list-style-type: none"> <li>1. <b>Transverse flux induction heating of thin metal strips:</b> <u>no dedicated institutional funding</u>; funding only from commercial contracts</li> <li>2. <b>Optimisation techniques applied to the design of induction heating inductors:</b> Institutional funding from PRIN 2000/2002: 28.405 €; from “Ricerca scientifica fondi quota ex 60%” 2001: 3615 €. In total: 32.020 €</li> <li>3. <b>Re-heating of aluminium alloys thixocasting billets:</b> <u>no dedicated institutional funding</u>; funding from commercial contracts</li> <li>4. <b>Development of single or double-frequency longitudinal levitators:</b> Institutional funding from “Ricerca scientifica fondi quota ex 60%” anni 2002, 2003 e 2004: 12.313 €.</li> <li>5. <b>Resistance heating of curvilinear workpieces:</b> <u>no dedicated institutional funding</u>; funding from commercial contracts</li> <li>6. <b>Single- or double-frequency induction hardening of gears:</b> Institutional funding from “Ricerca scientifica fondi quota ex 60%” anno 2005: 5.923 €.</li> <li>7. <b>Shielding of induction heating systems regarding EM field human exposure:</b> <u>no dedicated institutional funding</u>; funding from commercial contracts</li> <li>8. <b>Innovative High Efficiency Technologies for Induction Heating of Aluminium Strips and Billets:</b> Institutional funding from PRIN 2005: 51.000 €</li> <li>9. <b>Biomedical applications of heating by electromagnetic sources:</b> <u>no dedicated institutional funding</u>.</li> <li>10. <b>Important projects in the frame of contracts with industrial partners:</b> funding from commercial contracts</li> </ol>
6	<b>Research Facilities</b> <b>Risorse materiali</b>
6.a	<p><b>The Laboratory for Electroheat (LEP): Hardware and software facilities</b></p> <p>The Laboratory for Electroheat has been established in 1969 by professor Ciro Di Pieri with the aim to develop both theoretical research and experimental one. For this reason in the laboratory are present both computation and experimental facilities. The surface of the laboratory is about 90 sqm.</p>

	<p>Experimental facilities:</p> <ul style="list-style-type: none"> <li>✓ Power supply P=100 kW f= 450 kHz (triode generator)</li> <li>✓ Power supply P=100 kW f=9800 Hz (rotating generator)</li> <li>✓ Power supply P=100 kW f=1-4 kHz (SCR generator)</li> <li>✓ Power supply P=2 kW f=100 kHz (IGBT generator)</li> <li>✓ Infrared camera for temperature measurements</li> <li>✓ Pyrometer</li> <li>✓ Power analyzer for frequency range up to 100 kHz</li> <li>✓ Rogowsky probes for high frequency current measurements</li> <li>✓ Movement system for heating of strips by means of Transverse Flux method</li> <li>✓ Several inductors for experimental tests</li> <li>✓ Data logger for automatic acquisition of experimental data</li> </ul> <p>Computation facilities</p> <ul style="list-style-type: none"> <li>✓ Several workstations dual Pentium processor based with high RAM capacity</li> <li>✓ Flux 3D and flux 2D licenses for electromagnetic and thermal problems solutions</li> <li>✓ FEMLAB for MHD problems solutions snf for high frequency electromagnetic problems solutions</li> <li>✓ Amira for preparation of hypethermia models and for results visualization</li> <li>✓ Matlab Pspice and other system simulation software</li> <li>✓ Software for elaboration of infrared camera images</li> </ul>
7	<p>Collaborations with other Research Institutions Rapporti con altri istituti di ricerca a livello locale, nazionale e internazionale</p>
7.a	<p><b>Official cooperation links</b></p> <p>❖ <i>International cooperation:</i></p> <p>in the frame of official agreements:</p> <ul style="list-style-type: none"> <li>◆ Electrotechnical University LETI of St.Petersburg – Russia (of this University prof. Lupi is Honorary professor). The Russian responsible person is prof. Yu. Blinov</li> <li>◆ State Technical University of Novosibirsk – Russia. The Russian responsible person is prof. A. Aliferov</li> <li>◆ UIE – International Union for Electricity Applications</li> </ul> <p><u>Note:</u> An official agreement exists in the frame of the Erasmus programme with the University of Hannover (Germany); the close links developed in the years have produced also a very fruitful research cooperation with professors of the Institute for Electrothermal Processes (prof. A. Muehlbauer, prof. B. Nacke and prof. E. Baake).</p>
7.b	<p><b>Personal links</b></p> <p>❖ <i>At national level:</i></p> <p>Cooperation in the frame of the national projects PRIN 2000 and PRIN 2005:</p> <ul style="list-style-type: none"> <li>□ University of Genova (prof. G. Molinari)</li> <li>□ University of Pavia (proff.A. Savini and P. DiBarba)</li> <li>□ University of Bologna (prof. F. Negrini)</li> <li>□ University of Roma “La Sapienza” (prof. G. Veca)</li> </ul>

	<ul style="list-style-type: none"> <li>❑ Borgo Trento Hospital - Verona (in the field of Hyperthermia - Dr. Sergio Maluta – Director of Radiotherapy division of the same hospital)</li> <li>❑ Comune di Padova – (Scientific Committee on Human Exposure to Electromagnetic Fields)</li> </ul> <p>❖ <i>At international level</i></p> <ul style="list-style-type: none"> <li>❖ University of Hannover, Institute for Electrothermal Processes (prof. A. Muehlbauer, prof. B. Nacke and prof. E. Baake). <i>See note at point 7.b International cooperation</i></li> <li>❖ State University of San Paolo, Campus of Guaratinguetà – Brasil. (prof. M. Nunes Alves)</li> <li>❖ C.I.T. – Center for Induction Technology (prof. V.S. Nemkov former professor at the Electrotechnical University LETI of St.Petersburg)</li> </ul>
9	<p>Other activities relevant to the research programme          Altre attività rilevanti per la ricerca, a livello di Programma</p>
	<p><b>Other relevant activities</b></p> <p><b>9.a</b> - The Laboratory for Electroheat LEP organises in Padua each three years an International Symposium devoted to Induction, Conduction and Dielectric Heating. The following editions of the symposium have been held:</p> <ul style="list-style-type: none"> <li>- <b>IHS-98</b> - “Induction Heating Seminar”: 110 participants from 16 countries, 68 papers presented, 555 pages of proceedings.</li> <li>- <b>HIS-01</b> – “Heating by Internal Sources”: 140 participants from 20 countries, 91 papers, 685 pages of proceedings.</li> <li>- <b>HES-04</b> – “Heating by Electromagnetic Sources”: 160 participants, 95 papers, 723 pages of proceedings.</li> </ul> <p><b>9.b</b> – In the year 2004 the Laboratory for Electroheat LEP has organised an <b>Intensive International PhD Course on “Induction Heating and Electromagnetic Processing of Materials”</b>, with attendance of 15 PhD students coming from 7 Countries. Lectures were given by prof. A. Mühlbauer and prof. Baake (University of Hannover - Germany), prof. D. Lavers (University of Toronto – Canada) and prof. F. Dughiero (LEP).</p> <p><b>9.c</b> – In June 2005, prof. Lupi and prof. Dughiero have been invited and have given lectures on the “Theory and applications of induction heating” at the University of Bologna for PhD students of the Department of Electrical Engineering.</p> <p><b>9.d</b> – Prof. Lupi has been invited to give introductory presentations on the state of art at the following international conferences:</p> <ul style="list-style-type: none"> <li><b>a</b> “Workshop on the Role of Electrical Technologies in Achieving Sustainable Development and Creating Business Opportunities” (Eurelectric, Bruxelles, Belgium, Nov. 2001), see Ref. 9</li> <li><b>b</b> “EPM 2003 – Electromagnetic Processing of Materials” (Lyon, France, Oct. 2003), Ref. 27</li> <li><b>c</b> “UIE 2004”, (Durban, South Africa, Jan. 2004), Ref. 38</li> </ul> <p>Moreover, on May 2005, he has given an invited conference at the Electrotechnical University LETI of St. Petersburg (Russia) – where he is Honorary Professor – on “The Activity of the Electroheat Laboratory of Padua University”</p>
11	<p>Research products          Prodotti della ricerca (see <b>APPENDIX 1</b>)</p>

11.b	<b>RESEARCH PRODUCTS</b>						
		<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>Total</b>
	<b>Journal papers</b>	1	1	4	2	4	12
	<b>Chapters in book</b>	-	-	-	1	-	1
	<b>Books/Notes/Reports *</b>	-	-	-	1	-	1
	<b>Proceedings of Conferences **</b>	10	4	8	5	6	33
	<b>Patents</b>	-	-	-	-	-	-
	<b>Other</b>	-	-	-	-	-	-
* Edited in Novosibirsk, in Russian ** 4 invited ; 1 best poster award							
11.c	<ul style="list-style-type: none"> <li>❑ Dughiero F., Lupi S., Muehlbauer A., Nikanorov A.:  "TFH - Transverse flux induction heating of non-ferrous and precious metal strips: results of a EU research project"  <i>COMPEL Journal, (2003), vol.22, n.1,134-148</i></li>   <li>❑ Lupi S., Aliferov A.:  "Direct Resistance Heating of Metals"  <i>Book in Russian, Editor: Novosibirsk State Technical University (ISBN 5-7782-0475-2), (2004), 1,223.</i></li>   <li>❑ Dughiero F., Corazza S.:  "Numerical simulation of thermal disposition with induction heating used for oncological hyperthermic treatment"  <i>Medical &amp; Biological Engineering and Computing,, Vol. 43, 2005, pp. 40-46</i></li>   <li>❑ Lupi S., Dughiero F., Forzan M.: "LEP - Laboratory for Electroheat of Padua University" <i>HES-04 - Heating by Electromagnetic Sources (Padua, June 22-25, 2004), (2004), I, XXI-XXXII;</i>  <i>Reprinted on: Elektrowaerme International,Vulkan-Verlag Essen (Germany), n.1, March 2004, 30-36 (ISSN 0340-3521-K5548-F)</i></li>   <li>❑ Lupi S., Bonollo F., Forzan M., Schiavon M.: "Innovative induction heating installation for re-heating thixocasting billets up to 5 in. diameter: thermal and metallurgical results"  <i>Proc. of REI'05 (Katowice - Poland, Aug.31-Sept.3, 2005), I, 47-54;</i>  <i>Reprinted on: Archives of Electrical Engineering (Poland), (2005), vol. LIV, n.4,397-407</i></li> </ul>						

## APPENDIX 1 - REFERENCES

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## **APPENDIX 2 -**

### **RESEARCH CONTRACTS 2001-2005**

**Resp. Prof. S. Lupi**

**Resp. Prof. F. Dughiero**

#### **PROGELTA S.r.l.**

Titolo: "Studio del dimensionamento di un sistema di riscaldamento ad induzione per una siviera di colata"

Responsabile scientifico: Sergio Lupi

Importo: lire 10.000.000

Durata: 3 mesi

C.d.D.

Stipulato: 17/07/2001

#### **ELVI S.r.l.**

Titolo: "Utilizzo di metodi numerici orientati all'analisi delle prestazioni di motori amgneti permanenti"

Responsabile scientifico: Fabrizio Dughiero

Importo: lire 55.000.000

Durata: 12 mesi

C.d.D.

Stipulato: 05/09/2001

#### **PLANTEX S.p.A**

Titolo: "Analisi ottimizzazione e prove sperimentali su rulli riscaldati ad induzione per il trattamento di filati di materiali tessili"

Responsabile scientifico: Sergio Lupi

Importo: lire 50.000.000

Durata: 12 mesi

C.d.D. 29/01/02

Stipulato: 02/04/01

#### **Pietro Galliani S.p.A**

Titolo: "Analisi di fattibilità di un trattamento ad induzione a flusso trasverso per la ricottura di nastri d'argento"

Responsabile scientifico: Fabrizio Dughiero

Importo: euro 7.800,00

Durata: 3 mesi

C.d.D. 20/05/02

Stipulato: 20/06/02

#### **SITOS S.r.l.**

Titolo: "Analisi delle temperature e dei flussi d'aria in una macchina per la produzione in automatico della pizza"

Responsabile scientifico: Fabrizio Dughiero

Importo euro 15.000,00

Durata: 4 mesi

C.d.D. 20/05/02

Stipulato: 24/06/02

**HEMINA S.p.A.**

Titolo: "Utilizzo di metodi numerici orientati all'analisi e all'ottimizzazione delle prestazioni di sensori elettromagnetici di portata"

Responsabile scientifico: Fabrizio Dughiero

Importo: euro 16.000,00

Durata: 8 mesi

C.d.D. 20/05/02

Stipulato: 11/09/2002

**SITOS S.r.l.**

Titolo: "Sviluppo e ottimizzazione di processi di riscaldamento elettrico innovativi per la formatura, lievitazione e cottura della pizza"

Responsabile scientifico: Fabrizio Dughiero

Importo euro 38 750,00

Durata: 12 mesi

C.d.D. 01/03/02

Stipulato: 10/04/02

**SITOS S.r.l.**

Titolo: Ottimizzazione e isolamento termico di un forno a sorgenti infrarosse e induzione elettromagnetica per la cottura di alimenti

Responsabile scientifico: Fabrizio Dughiero

Importo euro 22.000,00

Durata: 8 mesi

C.d.D. 17/04/03

Stipulato:

**Contratto di consulenza. ATE S.R.L.**

Titolo: Progettazione di un prototipo di induttore per il riscaldamento di nastri di acciaio C45 sopra la temperatura di Curie e relative verifiche sperimentali

Responsabile scientifico: Sergio Lupi

Importo euro 24.000,00

Durata: 6 mesi

C.d.D. 10/02/04

Stipulato: 25/02/2004

**Contratto di ricerca con S.I.P.A SOCIETÀ INDUSTRIALIZZAZIONE PROGETTAZIONE AUTOMAZIONE S.P.A**

Titolo: Progettazione di un prototipo di induttore per il riscaldamento di preforme in PET e relative verifiche sperimentali

Responsabile scientifico: Fabrizio Dughiero

Importo euro 10.000,00

Durata: 6 mesi

C.d.D. 30/03/04

Stipulato: 19/04/2004

**Contratto di consulenza. STALAM S.p.A.**

Titolo: Caratterizzazione di pannelli radianti per applicazioni industriali mediante termocamera e spettrofotometro

Responsabile scientifico: Fabrizio Dughiero

Importo euro 5.500,00

Durata: 3 mesi  
C.d.D. 29/11/04  
Stipulato:

Contratto di consulenza **Ceramica Stefani S.r.l.** . (Allegato n. 2)

Titolo: “Studio di fattibilità e progettazione di massima di pannelli radianti in ceramica per applicazioni domestiche”.

Responsabile scientifico: Fabrizio Dughiero

Importo euro 15.000,00

Durata: 8 mesi

G.d.D. 17/05/05

Stipulato:

Contratto di ricerca **ILVE S.p.A.**

Titolo: “Progettazione verifica sperimentale di un prototipo di forno a cottura combinata microonde e resistori per uso domestico”

Responsabile scientifico: Fabrizio Dughiero

Importo euro 35.000,00

Durata: 12 mesi

G.d.D. 25/07/05

Stipulato:

Contratto di ricerca **WHIRPOOL EUROPE S.p.A.**

Titolo: “Ricerca sulle applicazioni domestiche del riscaldamento ad induzione e possibili innovazioni”

Responsabile scientifico: Fabrizio Dughiero

Importo euro 35.000,00

Durata: 12 mesi

G.d.D. 23/09/05

Stipulato: 13/10/05

Contratto di consulenza **BANCA DI CREDITO COOPERATIVO DI PIOVE DI SACCO – Società Cooperativa.**

Titolo: “Studio di fattibilità, analisi economica e progettazione di un sistema per la produzione di energia elettrica attraverso lo sfruttamento di energia Fotovoltaica”

Responsabile scientifico: Fabrizio Dughiero

Importo euro 19.000,00

Durata: 8 mesi

G.d.D. 22/11/05

Stipulato:

Contratto di ricerca **HEMINA S.p.A.**

Titolo: “Studio e ottimizzazione delle prestazioni di sensori di portata ad ultrasuoni”

Responsabile scientifico: Fabrizio Dughiero

Importo euro 18.000,00

Durata: 6 mesi

G.d.D. 22/11/05

Stipulato: