Applied MHD at the University of Bologna

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ABSTRACT — Recent MHD activities at the Department of Electrical Engineering of the University of Bologna are summarised.

I. INTRODUCTION

Following the Italian National Program on Superconducting Magnets (CNR supported Project "SuCryTec" 1990÷1996), mainly concentrated on MHD magnets and high field magnets, some new activities started in the Department of Electrical Engineering of the University of Bologna, with the aim to analyse different electric power applications of MHD Sciences and superconducting technologies.

A follow-on effort is planned, in particular concerning MHD processing of materials, S.C. magnetic separators and superconducting systems for energy storage. In this communication, some information about these topics are given.

II. ELECTROMAGNETIC PROCESSING OF MATERIALS

The "Electromagnetic Processing of Materials (EPM)" is based on both MHD and Process Metallurgy. Application of electromagnetic forces to materials processing, which constitutes EPM, has been recognised as an edge technology, especially in the fields of steelmaking and advanced materials processing. In metallurgy many process involve the handling of liquid metal in a technologically difficult environment. It's apparent that by use of the MHD effects, that is by a suitable application of the **J**×**B** force, improvements in existing processes or new solutions of old problems may be achieved. An example of the successful application of the MHD processes in the metallurgical processing is the electromagnetic stirring. Actually devices like electromagnetic stirrers and brakes are commercially available for alloys of aluminium, magnesium , zinc, copper, etc.

A cold crucible is a typical application of the magnetic pressure in metallurgical processes. It is composed of three parts: a charge to be melted, a water-cooled and segmented copper crucible and an induction coil as shown in Fig. 1.

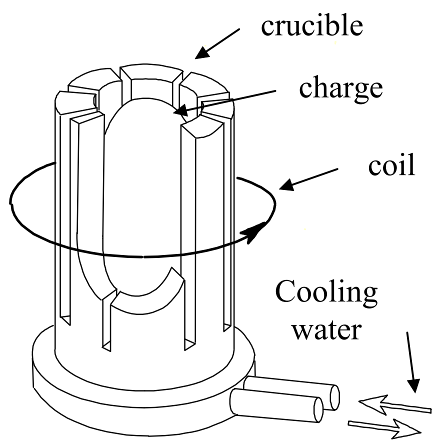

Fig. 1. - Cold crucible scheme.

As a charge is levitated using magnetic pressure, this process enables the melting of a charge without contamination from the crucible under an arbitrary atmosphere. Thus, the cold crucible is indispensable for melting metals with a high melting point and chemically reactive properties.

Studies on the stability of meniscus, by using a cold crucible as experimental apparatus, have been carried out at the Department of Electrical Engineering of the University of Bologna in co-operation with the Futtsu NSC laboratories in Japan.

The electromagnetic shaping and stabilisation of the steel meniscus in the mold is a key point in the electromagnetic casting. The frequency has been varied in the range 5 - 20 kHz The oscillation of meniscus at the axis position has been measured by a laser sensor. The standard deviation of the meniscus height is reported in Fig. 2 varying inductor coil voltage. As it's expected, the meniscus is more stable at high frequency (20 kHz). Moreover, a strong instability, called dancing motion, has been observed. The origin of this phenomena, occurring only for low frequency and voltage, is probably connected with a resonance effect as suggested from the FFT analysis of laser data.

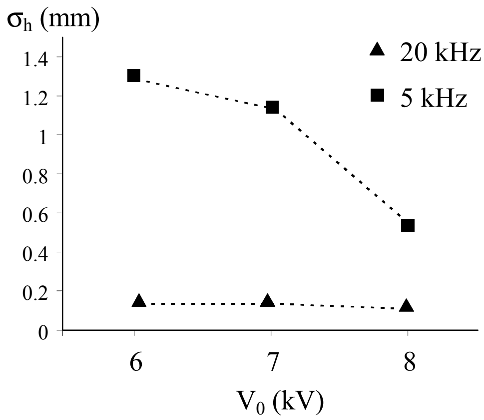

Fig.2. - Standard deviation of the meniscus height on the symmetry axis.

The equilibrium equation for the meniscus has been solved to compute its shape. The error between computed shapes and experimental ones is lower then 10%. The meniscus shape can vary strongly and non linearly with frequency and voltage. In Fig. 3 two shapes, obtained varying frequency, are shown.

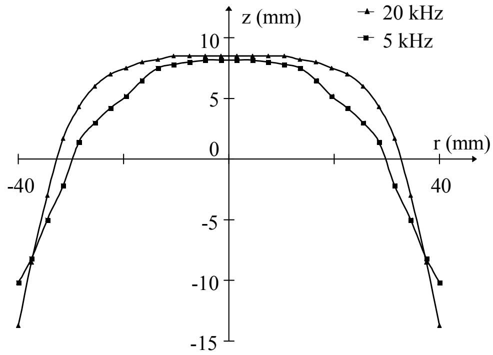

Fig.3. - Meniscus shapes for two frequencies.

Referring to casted steel, the optimal design of the meniscus shape can lead to the improvement of the surface quality of continuously casted steel that is indispensable for directly connecting the continuous casting stage to the rolling stage. This would provide a large amount of energy saving due to the elimination of the process of re-heating slabs and the process of surface treatment.

The electromagnetic shaping has been investigated not only for casting but for coating, also. The control of the shape of a flowing film of liquid metal using the electromagnetic force have been studied in co-operation with the Laboratory of Fluid Sciences of the Tokyo Institute of Technology.

The experiments have been carried out at room temperature with mercury. The aim of the experiment was to obtain a controlled widening and a consequent decrease of the thickness of the metal flow using a relatively simple apparatus. Two magnets have been placed in a "V position" under the inclined channel in which the mercury flows, as it's shown in Fig.s 4 and 5.

Changing the angle (α) between them leads to a modification of the force produced by the interaction of the steady magnetic field (0.4 T) and the electric current passing through the metal (15 - 30 A).

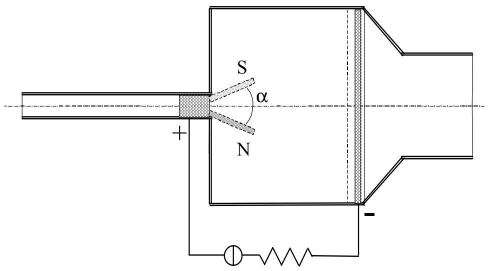

Fig. 4. - Scheme of the experimental apparatus.

Fig. 5. - Photograph of the flowing out jet.

Since both sides of the running liquid are not constrained by solid walls the shape of the mercury flow is easily changed by the electromagnetic force. As it is shown in Fig. 6, under particular values of electric current and angle α the flow becomes five times wider than before the application of the force.

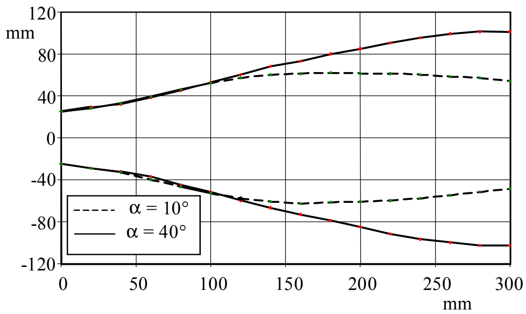

Fig. 6. - Widening of the flow.

Applications of this research are in the production processes of metal sheets and particularly in the use of an electromagnetic wiping force in the hot dip galvanizing lines of flat steel instead of the traditional pneumatic process.

III. MAGNETIC SEPARATION

The technique of high intensity and high gradient magnetic separation offers the solution to various complex problems in many fields of engineering and technology. Although magnetic separation constitutes an old and established technique for the treatment of strongly magnetic ores and the removal of ferromagnetic impurities from mixtures, the advent of high gradient magnetic separators (HGMS) has been one of the most significant advance in the handling of small particles in the last 20 years. The development of the superconducting magnet technology gives the possibility to produce a high magnetic flux density in a large volume at low energy consumption. Therefore the treatment of suspension of sub-micron and weakly magnetic particles is possible by means of high gradient magnetic separation.

Many industrial applications can have significant benefit from the developing of S.C. magnetic separation technology:

- weakly magnetic mineral treatment. The separation and removal of mineral contaminants from kaolin, a white clay used extensively in paper processing, can be cited as example;
- coal treatment;
- particle removal from the fumes produced in arc furnaces;
- particle removal from combustion gas;

- particle removal from sewage water;
- nuclear waste removal from desert soil and cooling basin water.

S.C. magnetic separators too are near to a full commercialisation phase: well functioning LTSC prototypes for open gradient and for high gradient magnetic separators have been operated in the late ‘80s. Just recently (July 1996) DuPont announced the commercialisation of an HGMS utilising an HTSC magnet built by Sumimoto Electric Ind. for the treatment of kaolin.

Studies on matrix HGMS has been carried out at the Department of Electrical Engineering at the University of Bologna. The field gradient in a matrix HGMS is caused by the presence of an array of ferromagnetic wires (see fig. 7).

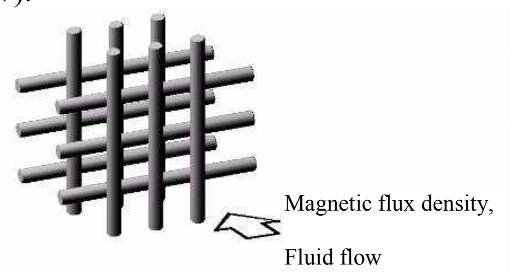

Fig. 7. - Schematic view of a matrix in a HGMS.

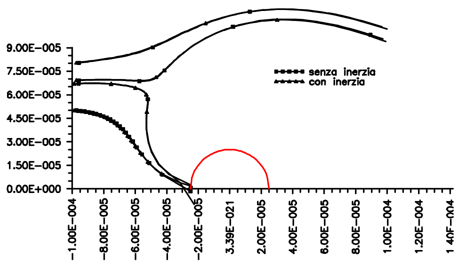

Fig. 8.a. - Trajectories for paramagnetic particles.

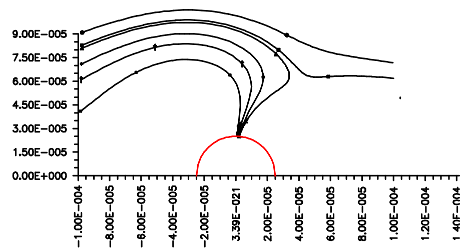

Fig. 8.b. - Trajectories for diamagnetic particles.

The particle suspended in the fluid flowing through the matrix is subject to a magnetic force and a fluid dynamic drag force. When the magnetic forces wins over the drag, the particle land on a matrix wire and is captured. The equation of motion for a particle in a HGMS grid has been solved. The trajectories obtained for a paramagnetic and diamagnetic particle are shown in figures 8.a and 8.b. The obtained capture parameters has been utilised to calculate the particle retention in magnetic filter. The results are shown in figures 9.a and 9.b.

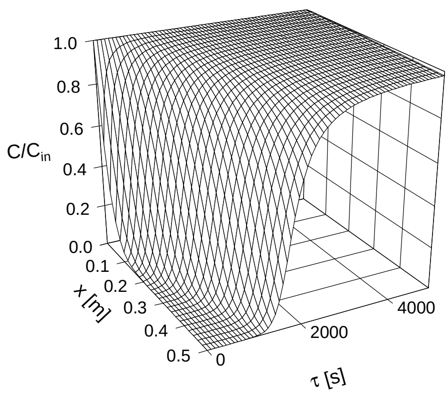

Fig. 9.a. - Loading of a magnetic filter: the time behaviour of the ratio between the particle concentration in the fluid C and the inlet particle concentration C_i along the axis of the filter is shown.

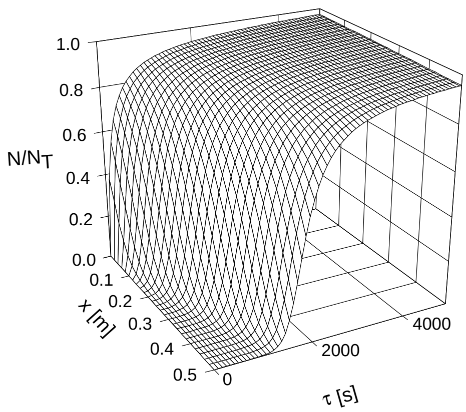

Fig. 9.b. - Loading of a magnetic filter: the ratio between the captured particle concentration N and the saturation value N_T for the captured particle concentration is shown.

IV. Superconducting systems for energy storage

Energy storage is becoming more and more important in modern electric power systems. A great amount of electric power is needed in many industrial applications, as metallurgical ones, in a discontinuous way, and energy storage capabilities are required to maintain the power quality of the electrical energy distribution. Energy storage for load levelling is important to better utilise the existing power plants and distribution grids, with consequent reduction of the environmental impact due to new installations. The consequences of a voltage outage or a voltage sag, even of a small duration (250 ms), can be disastrous for a modern manufacturing industry, where electromechanical control has been replaced by digital equipment ; Uninterruptable Power Supply (UPS) systems are then required.

Superconducting technology is competitive with the traditional ones in many of the above mentioned applications of energy storage, in particular:

- micro-SMES (Superconducting Magnetic Energy Storage) systems, in the range till to 0.1 MWh of stored energy, seems very attractive for power quality applications against the voltage outages and the voltage sags and to control the active and reactive power flow, due to their fast response to the electric power demand;
- high temperature superconductors can be utilised to magnetically levitate flywheel systems with a significative improvement of their efficiency, which make them attractive for load levelling purposes.

Micro-SMES system

A research project has been started in 1997 for the study of a micro-SMES system which should protect sensitive industrial processes against short voltage outages and voltage sags. The system should also provide active and reactive power control. The research activity is mainly devoted to the power electronic equipment which connects the superconducting coil with the electrical grid. The goal of the project is the design, construction and test of a prototype in the range 0.1 - 10 kWh, with IGBT (Insulated Gate Bipolar Transistor) technology. The electromagnetic compatibility aspects of the prototype will be studied and tested too. As much as the superconducting coil is concerned, particular attention will be devoted to the optimal electromagnetic design, with regard to the stray field of the system, and to the modelling of a.c. losses phenomena in the CICC cable during the charge and discharge of the system.

High temperature superconducting bearings for a flywheel energy storage system

The goal of the research activity is the optimal design of a flywheel energy storage system. In particular the attention is devoted to the high temperature superconducting magnetic levitation system which is made by permanent magnets, which are positioned on the flywheel, and Yttrium Barium Copper Oxide (YBCO) samples on the support of the system. As a first step toward the modelling of the dynamic response of the system an axial symmetry system is considered. The screening currents into the high temperature superconductor are described by means of the electrical vector potential and the flux flow and flux creep model. The research activity is being developed in co-operation with CISE (Research Centre of the Italian National Electrical Utility in Milan), as much as the experimental activities are concerned.

V. CONCLUSIONS

Some new activities which started in the Department of Electrical Engineering of the University of Bologna, with the aim to analyse different electric power applications of MHD Sciences and superconducting technologies, are reported.

Numerous other activities regarding the MHD Electrical Power Generation have been carried out during 1996/97 resulting in the papers that are reported in the references.

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