AUSTROMAG – high field set up and experiments

R Grössinger, M Schönart, M Della Mea and H Sassik
Inst. of Solid State Physics, T.U. Vienna; Wiedner Hauptstr. 8-10; A-1040 Austria
rgroess@ifp.tuwien.ac.at

Abstract. Austromag offers high magnetic fields for various applications in solid state physics. The quasistatic high field facility gets the power (10 MWs) from the line of the city, reaching 40T in a long pulse (up to 1s). Additionally exist various short pulse facilities (pulse duration between 10 and 100 ms) which are energized by a condensor battery. New types of high field magnets (foil coil) were developed. Measurements are possible between 4.2 K and 800 K. The main experiments are: magnetization, magnetoresistence, anisotropy and magnetostriction. New measuring techniques were developed such as pressure dependence of anisotropy and magneto-electric coefficient.

1. The Austromag system
(T.U.Vienna) consists of four different machines:
Quasistatic The “Austromag” high field installation which is situated at the Inst. of Solid State Physics high field system; Short pulse system (75 kJ); Industrial pulsed field system; Short pulse system (440 kJ).

1.1 Quasistatic System
The power for generating quasistatic high magnetic fields comes directly from the line. The primary power at the 10 kV level of the transformer needs up to 16 MVA. The transformer delivers at the secondary side 2 x 840V. The maximum regulated dc-power is 10 MW over 1s. With the thyristor regulator the current versus time profile can be chosen - with 20 free points which define the profile. Details of the power supply were described in [1,2].
The chosen I(t) profile is checked with respect to the generated heat within the thyristor bridge as well as the heating of the magnet. Also all switches and changeable connections are surveyed - only if the circuit is in a proper operating condition the system allows to generate the current pulse.
The system produces depending on the hardware switching of the thyristor bridges- three types of pulses:
i) parallel switching: 2 x I_{max} = 10 kA, U_{max} = 840V; field -pulse with one polarity.
ii) Serial switching: I_{max} = 10 kA, 2 x U_{max} = 840V – higher voltage; field pulse of one polarity;
now used for generating the highest fields (40T).
iii) Antiparallel switching: I_{max} = ± 10 kA, U_{max} =± 840V. Bipolar pulse – necessary for real hysteresis measurements.
The high field magnets
The pulse magnet has to be optimised with respect to the available power, the heating of the magnet and the stresses. The magnet is generally operated in liquid nitrogen (77K). The field homogeneity over 30 mm is better than 1%. In the installation three different magnets are used.

i) The magnet for the high temperature system is limited to a maximum field of 32 T however in a bore of 60 mm. Inside of the bore the high temperature set-up (furnace, measuring set-up) is located.

ii) The 40T magnet (25 mm bore) was delivered by Metis. This magnet is reinforced by carbon glass. The measuring device and the sample is located in a nonmagnetic stainless steel cryostat from Cryogenics with a tail with an inner diameter of 12mm.

iii) The third magnet is used for the development of new measuring techniques. It delivers during tests at T = 77 K a bipolar maximum field of 25T in a bore of 30 mm with a plateau time of 200 ms.

Recently a new type of high field magnet was developed. The magnet was produced by thin Cu-foils (0,15 mm; N = 560) which were isolated by 12 μm Hostaphan foil. With this magnet reproducible fields up to 35T with the quasistatic Austromag system were achieved [3]. The stress at the mid-plane of the magnet was measured using a strain gauge method.

For measuring the pulse current I(t) a Rogowski-coil system was developed and installed. The field can be measured with a hall probe (LHP-NA; AREPOC Ltd) which is linear up to 35 T. Plotting I(t) versus H(t) allows to detect mechanical deformations in the pulse magnet.

In the quasistatic system the following magnetic properties can be measured:
Hysteresis loop (magnetization) from 4.2 K up to 800 K; magnetostriiction using a strain gauge method with a 50 kHz bridge; magnetoresistence. In order to increase the signal to noise ratio for magnetization measurements, a modulation method was developed. With an additional field coil a small ac-field (using a frequency between 1kHz and 10 kHz) is superimposed. In the pick-up coils an ac-voltage proportional to the magnetization is induced, which can be measured with a lock-in amplifier. With this method the thyristor noise of the quasistatic Austromag, which appears in all measuring devices, can be reduced.

1.2 Short pulse systems
There are three condensor operated short pulse systems. Tale 1 summarises the technical parameters of the systems.

Table 1: Technical parameters of the short pulse field systems; C (capcitance), U max (maximum charging voltage), W (stored energy, μ0H max (maximum achievable field), D (available bore diameter), t pulse (pulse duration for sin full wave), T operating (range of operating temperature).

| System          | C (mF) | U max (V) | W (kJ) | μ0H max (T) | D (mm) | t pulse (ms) | T operating (K) |
|-----------------|--------|-----------|--------|--------------|--------|--------------|-----------------|
| Industrial      | 4      | 3000      | 22.5   | 5            | 30     | 40,57        | 300             |
| Short Pulse I   | 25     | 2500      | 75     | 30           | 25     | 10           | 4.2 - 700       |
| Short Pulse II  | 14     | 8000      | 440    | 40           | 25     | 10-100       | 4.2-300         |

1.2.1 Industrial pulsed field system
The industrial pulse field system was designed by Hirst within an EC project (MACCHARACTEC (European 4th Framework); project number SMT4-CT98-2212) [4]. The target was to investigate the possibility to design a reliable industrial pulsed field magnetometer for the quality control of permanent magnets. The whole charging process, f/2f selection and the data acquisition is computer controlled. The signal is integrated with stable analogue integrators with selectable time constants. The signals are connected to a 14bit 5Msample/s two channel ADC card (Datel; PCI-416) directly in a computer. The pulse magnet is divided into two magnet sections which can be pulsed independently.
providing a long or short pulse duration, conventionally named f and 2f (40 and 57 ms pulse duration) which allows to correct for eddy current errors [5]. Accurate room temperature hysteresis measurements on large permanent magnets (up to 30 mm) are possible. Room temperature measurements of the magnetostriiction on polycrystalline Ni, Fe and on CoFe$_2$O$_4$ using a strain gauge method (50 kHz bridge) demonstrated the usefulness of this method. First measurements for determining the magneto-electric coefficient on multiferroic composites (50% CoFe$_2$O$_4$ + 50% BaTiO$_3$) in pulsed fields were performed. Applying a field pulse $H(t)$ generates a voltage $V(t)$ (charge) which can be measured directly on the surface of the multiferroic sample [6].

1.2.2 Short pulse system I (75 kJ)
With this system the temperature dependence of hysteresis (magnetization) as well as the anisotropy field using the SPD technique [7,8] can be determined. From hysteresis loop measurements with varying $dH/dt$ the magnetic viscosity of hard magnetic materials was estimated [see e.g. 9]. Recently a pressure cell, made of MP35N steel, was developed. This device allows to measure the pressure dependence of the anisotropy field (up to 10 kbar) using the SPD technique. The reduction of the maximum field due to eddy currents was less than 5% (pulse duration 10 ms). In order to demonstrate this new possibility Fig. 1 shows the measured pressure dependence of the anisotropy field of BaFe$_{12}$O$_{19}$ (barium ferrite).

![Graph showing pressure dependence of BaFe$_{12}$O$_{19}$](image)

**Fig.1 Pressure dependence of BaFe$_{12}$O$_{19}$ measured at 77 K and 300 K using the SPD technique.**

1.2.3 Short pulse system II (440 kJ)
The aim of this extension is to produce later by a superposition of a short field pulse on the quasistatic field a total maximum field of 60 - 70T. This follows ideas [10] proposed by several high field specialists in Europe but also in USA; with a long time pulse a back ground field of about 30T is produced which is during 100 ms available in a bore of about 40 – 60 mm. Because the inserted short time pulse magnet is generally small compared with the outer magnet, the field effect on the outer magnet is (almost) negligible. This means that the outer magnet can be made of simple Cu or Cu-Ag windings - it is only a 30T magnet! Inside this bore a reinforced pulsed magnet with a maximum field of 30 - 40T in a bore of 15-20 mm and a pulse duration of some ms shall be installed. This magnet has to be produced of a conductor with a very high yield strength - such as e.g. Cu-steel composite [11]. This small pulse magnet shall be energized with a condensor battery. For designing this system intensive force and optimization calculations for different geometries and available conductors have to be performed. Fig.2 shows the block diagram of the 440 kJ system. The charging, discharging
procedure is handled using a Labview program. For the data acquisition a 4 channel PC card with 16 bits resolution (model NI PCI 6120; National Instruments) is used.

Fig. 2 block diagram of the 440 kJ pulsed field system.

Acknowledgement
This work was partly supported by the Austrian Science Foundation under the project number P15737.

References
[1] Grössinger R, Kirchmayr H, Sassik H, Schwetz M, Taraba M, Frings P, Kaspar G and Raithmayr W 1999 J. Magn. Magn. Mat. 196-197 927
[2] Grössinger R, Sassik H, Hauser R, Wagner E, Reiterer K, Rzetecki P and Taraba M 2001 Physica B 294 –295 555
[3] Grössinger R, Keplinger F and Hauser H 2004 Physica B 346 – 347 604
[4] Dudding J, Knell PA, Cornelius RN, Enzberg-Mahlke, Fernengel W, Grössinger R, Küpferling M, Lethuillier P, Reyne G, Taraba M, Toussaint JC, Wimmer A and Edwards D 2002 J. Magn. Magn. Mat 242-245 1402.
[5] Jewell G W, Howe D, Schotzko C and Grössinger R 1992 IEEE Trans. Magn. 28 3114
[6] Giap V Duong, Groessinger R, Schönhart M and Bueno-Basques D Proc. JEMS 06 to be published
[7] Grössinger R, Sun X K, Eibler R, Buschow K H J and Kirchmayr H 1985 J. Physique 46 C6 - 221
[8] Grössinger R, Tellez Blanco J C, Kools F, Morel A, Rossignal M and Tenaud P 2000 Proc. of ICF8 on Ferrites (Kyoto, Japan), Ed. By Masanori Abe, Yohtaro Yamazaki 428
[9] Grössinger R, Tellez Blanco J C, Sato Turtelli R, Hauser R, Reiterer K and Sassik H, Chouteau G 2001 Physica B 294 –295 194
[10] Askenazy S 1995 Physica B 211 65
[11] Dupouy F, Askenazy S and Peyrade J M 1995 Physica B 211 43