A dedicated NMR apparatus for non-invasive and non-destructive measurements of great dimension cores

M. Gombia[a], V. Bortolotti[a], P. Schembri[a], G. Ferrante[b], S. Sykora[b] and P. Fantazzini[c]

[a] University of Bologna, Dept. DICMA, Viale Risorgimento 2, 40136 Bologna, ITALY
[b] Stelar S.r.l., Via E. Fermi 4, 27035 Mede (PV), ITALY
[c] University of Bologna, Dept. of Physics, Viale Berti Pichat 6/2, 40127 Bologna, ITALY,
E-mail: paola.fantazzini@unibo.it

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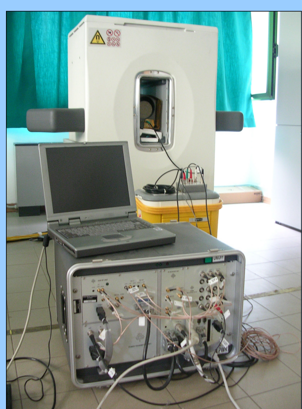
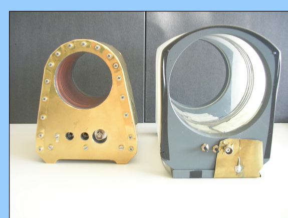
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Nuclear Magnetic Resonance Relaxometry is a universally accepted technique for the determination of structural and transport properties of porous media in a non-destructive and non-invasive way. In particular, it allows one to determine[1] porosity, permeability and irreducible water saturation. The increasing use of this methodology requires new types of equipment making it possible to investigate samples with particular characteristics, such as large, full-size cores. In order to perform relaxation measurements on full size cores, an apparatus has been designed and built. It is composed of a versatile SPINMASTER console, a permanent magnet with large bore and good field homogeneity over the whole sample volume, and several RF coils combining large volume with short dead time with high B_1 field homogeneity. The apparatus is compatible with the cores of up to 12 cm in diameter. To further improve the performance of the apparatus, we have implemented special measurement pulse sequences, such as Logarithmically distributed Aperiodic Pulse Saturation Recovery (LAPSR) and Inversion Recovery with Composite Inversion Pulse (IR-CP) and CPMG with Composite Inversion Pulses (CPMG-CP).

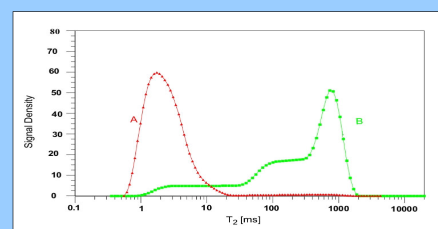
Experimental Setup





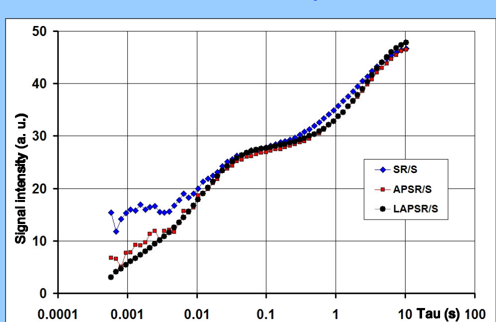
The main parts of the NMR system used in this work are (figure in the left):
- a portable version of Stelar SPINMASTER UNC/FFC universal Broad band console. This broadband RF console features an observing frequency ranging from 2 to 80 MHz, selectable with 0.01 Hz step digitally synthesized by means of two DDS. The quadrature receiver is composed by two independent 0°, 90° channels. The acquisition is done by means of two channels with 12 bit/10 MHz A/D converters. The power pulse transmitter is a 300 W RF Linear Amplifier. The Software used for both data acquisition and evaluation is the standard release AcqNMR V2.10.52 of Stelar for Spinamster systems;
- an Esaote Artoscan permanent magnet with a maximum magnetic field of about 0.2 Tesla originally designed for MR imaging. The magnet inhomogeneity is less than 50 p.p.m. over a sphere with a diameter of 9 cm;
- two detection solenoid coils (figure on the right), 75 and 120 mm in diameter respectively, specially designed to be used with the Esaote permanent magnet. Their total dead times vary from about 50 µs for the small coil to about 100 µs for the larger one at 7.6 MHz.

Evaluation of System Performance



In order to evaluate the system performance, we have performed measurements using phantoms with known NMR parameters, as well as non-consolidated cores (10 cm in diameter and 15 cm high). The Figure above shows two T_2 relaxation time distributions, obtained evaluating raw data by UPEN[2], for two different samples: sample A is a fine sand (on the left in the picture), while sample B (on the right) is a gravel. As expected, sample A is characterized by a single peak at very short times, whereas sample B shows a wide distribution covering three decades.

Comparison of the saturation recovery data obtained using various saturation methods



The acronyms stand for traditional Saturation Recovery (SR) using a single 90° pulse to create null the longitudinal magnetization ("saturate"), Aperiodic Pulse Sequence Recovery (APSR) using a series of 20 pulses separated by linearly decreasing intervals (the last one was 0.1 ms) and the Logarithmic Aperiodic Pulse Sequence Recovery (LAPSR) using also 20 pulses but with logarithmically decreasing intervals covering the range from 34.7 ms down to 0.05 ms. In all these sequences, the pre-saturation is followed by an interval of duration tau during which the sample magnetization follows the T_1 relaxation curve which is sampled by applying a final 90° pulse and acquiring the FID. In all cases, 64 such data point were measured using the multi-block (/S) versions of the sequences and distributing the tau values logarithmically between 0.5 ms and 12 s.
The sample was a phantom composed of two plastic containers, one with un-degassed distilled water (T_1 of 3.01 s) and the other of water doped with a Cu-Edta salt (T_1 of 12.1 ms), in approximately equivalent amounts. The operating frequency was 7.616 MHz and the 90° pulse width was 95 µs.
Comparing the three sequences in the order SR-APSR-LAPSR one sees a marked improvement of all parameters (quantitative values, fitting errors, etc). The SR sequence severely affects the short T_1 component with a pure saturation, due mainly to B_1 inhomogeneity over the large sample volume and even the T_1 of the long component is significantly off-mark. The APSR sequence is better but not as good as LAPSR which allows an almost perfect estimate of the short T_1 and even a clear hint of an even faster-decaying component represented by protons in the plastic containers.

REFERENCES

1 G.C. Borgia, V. Bortolotti, A. Brancolini, R.J.S. Brown, P. Fantazzini, Developments in core analysis by NMR measurements, Magn. Reson. Imaging, 14: 751-760 (1996).
2 G.C. Borgia, R.J.S. Brown, P. Fantazzini, Uniform-Penalty inversion of multiexponential decay data II: data spacing, T2 data, systematic data errors, and diagnostics, J. Magn. Res., 147: 273-285 (2000); ibidem, 132: 65-77 (1998).

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