Muons on request (MORE): combining advantages of continuous and pulsed muon beams

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A technique has been tested for the first time which combines the advantages of continuous and pulsed muon beams, namely high time resolution and low background in time-differential μ SR experiments. In addition, the method allows the muon beam to be split and two μ SR experiments run simultaneously at full intensity without any interference between the instruments.

1. Introduction

In conventional time-differential μ SR experiments, an ideal lifetime spectrum would contain only start-stop events belonging to the same muon. In real experiments using continuous muon beams, however, there is always a certain number of muons escaping detection, e.g., those stopping near but not hitting the muon counter. This results in a random rate of events in the start and stop channels and a random background in the muon-decay histograms, thus limiting the useful time interval to about 10 μ s and excluding investigations of low muon-spin precession frequencies or slow relaxation processes. Pulsed muon beams, on the other hand, deliver many muons per pulse at low repetition rates (e.g., 50 Hz at ISIS). In this technique, the time resolution is limited by the finite length of the muon pulses (80 ns at ISIS compared to 1 ns on the GPS instrument at PSI [1]). However, the background is typically three orders of magnitude lower.

A method to solve the background problem at continuous muon beams has been proposed earlier [2,3] for surface-muon beams at TRIUMF or KAON but has never been realised. The basic idea is to extract only one muon at a time out of a continuous beam by means of a fast-switching electrostatic deflector (“kicker”) on request from a μ SR instrument. This makes sure that no other muon reaches the spectrometer until the extracted one has been processed. Moreover, the concept of “Muons-On-Request” (MORE) does not significantly reduce the intensity of the original beam which is therefore available for the simultaneous use by a second spectrometer, i.e., MORE produces twice as many results of even higher quality (lower background in one spectrometer) than the conventional technique.

2. Experimental setup

The main components installed for MORE in the surface-muon beam line π M3 at PSI are shown in figure 1 together with the two instruments GPS (General Purpose Surface-muon spectrometer) and LTF (Low Temperature Facility).

The kicker contains two 1 m long, 20 cm wide electrodes 20 cm apart (figure 2). Two power supplies for dc voltages up to +5 kV and -5 kV are connected to the electrodes via fast switches, giving a difference of 20 kV between the two field directions and a separation of the muon trajectories of about 5 cm at the intermediate beam focus in front of the septum magnet located about 5 m from the kicker exit. Each switch consists of a series of 15 high-voltage MOSFET transistors type IXYS 6N100.

A 0.1 mm thick plastic scintillation counter placed at an intermediate beam focus inside the bending magnet ASK31 was used to trigger the kicker. Alternatively,

Figure 1. Layout of the π M3 surface-muon beam line at PSI for the muons-on-request (MORE) technique.

Figure 2. (a) Schematic circuit of the fast-switching deflector ("kicker") for muons on request. Power per switch ≤ 600 VA, repetition rate ≤ 40 kHz, voltage $|U| \leq 10$ kV between electrodes, switching time: < 25 ns (10–90%). (b) Driving circuit for one switch. Delay between trigger signal input and high-voltage output ~ 40 ns.

the muon detector (M-counter) in the spectrometer was used. The main differences between the two trigger sources are the times of flight between trigger and kicker, the different photomultiplier transit times (Hamamatsu R5600U subminiature in ASK31, R1828-01 for M-counter) and different cable delays. The kicker is switched to the spectrometer running in “MORE mode” (say, GPS) for a maximum of 5 μ s at a fixed repetition rate (max 40 kHz). The signal of the first muon hitting the trigger detector (either ASK31 or M-counter) after a minimum delay of 200 ns is used to switch the kicker back to the spectrometer running in “parasitic mode” (LTF in this case). The delay is necessary to avoid damage to the power switches.

Either instrument, GPS or LTF, can be used in MORE mode while the other one is running in “parasitic” mode. Two variable slits located in the intermediate focus plane of the beam in front of the septum magnet are used to adjust the event rate in both legs individually. The two instruments can also be used simultaneously in conventional “shared” mode by means of a horizontally defocused beam spot in the septum magnet slit plane.

3. Results and discussion

Figure 3 shows an example of μ SR in silver in an external magnetic field of 10 mT, taken with the GPS in MORE mode and using the trigger detector in ASK31. For comparison a conventional spectrum is shown taken at the same event rate. The background in MORE mode is at least a factor of 100 lower than in conventional mode, thus allowing the study of muon-spin precession and relaxation easily up to 20 μ s.

With the GPS M-counter as a trigger for MORE, a 6 times higher event rate was achieved, with only a marginal increase of the background B_0/N_0 (table 1). When using the ASK31 trigger detector, the event rate is reduced because the beam is kicked back to LTF even if the triggering muon does not reach the M-counter in GPS. This loss is due to muons stopped in the slits at the septum magnet and in the so-called backward veto detector located in front of the GPS M-counter. This detector acts as an active collimator with an opening of 7 mm $\times$ 7 mm, which is considerably smaller than the beam-spot size.

In MORE mode with M-counter trigger we observe a small distortion in the spectra at times $t \leq 450$ ns (insert in figure 3) which is due to the delay between the passage of the muon and the arrival of the trigger signal at the kicker. During this time, additional muons can enter the spectrometer and “kill” events through pile-up rejection. The distorted part is only about 200 ns shorter when the ASK31 trigger detector is used. In principle, fitting the distorted spectra is possible using different values of the fit parameters N_0 (normalizing constant) and B_0 (background) in the two regions. However, the MORE technique is preferentially used for slow signals where cutting off the first channels does not affect the data analysis.

Figure 3. μ SR in silver in a magnetic field of 10 mT measured at the GPS facility instrument in conventional and in MORE mode. *Insert*: Reduced asymmetry plot for the first 2 μ s in MORE mode (function fitted for $t \geq 0.4 \mu$ s).

Table 1
Comparison of results obtained with GPS in conventional and in MORE mode (using the detector in ASK31 or the GPS M-counter as trigger). Values for pulsed μ SR (ISIS) are also shown.

	Convent.	MORE	MORE	μ SR
Trigger	none	ASK31	GPS	50 Hz
B_0/N_0 (10^{-5})	660	6.3	8.7	~ 1
Time resol. (ns)	1	1	1	80
Event rate ($10^6/h$)	12	3.2	20	10–20

The unique new feature of the system is that – due to the high time resolution – it opens the possibility of studying *slow relaxation phenomena at high magnetic fields* and to *resolve close spin-precession frequencies*.

References

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