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Fits to data for a stored uncooled polarized deuteron beam

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ABSTRACT

I perform tracking simulations to fit various measurements of the polarization for a stored uncooled polarized deuteron beam, published in the recent paper by Benati et al. [P. Benati et al., Physical Review Special Topics—Accelerators and Beams 15 (2012) 124202]. The collaboration kindly sent me datafiles of the polarization measurements, and also pertinent details of the experimental data acquisition procedure. The latter are essential to obtain quantitative fits to the data. I describe my findings and inferences from the data. In some cases I offer alternative interpretations of the data from that given by Benati et al. [1]. I also correct some mistakes in my recent paper [S.R. Mane, Nuclear Instruments and Methods in Physics Research Section A 726 (2013) 104–112].

1. Introduction

In a recent paper, Benati et al. [1] presented results for spin resonances for a stored polarized deuteron beam, induced by an rf solenoid. The effects of synchrotron oscillations on the spin precessions were found to be significant. I published a recent paper [2] deriving analytical formulas for the synchrotron tune modulation of spin resonances induced by a localized rf solenoid or rf dipole. I published various analyzes of the data in Ref. [1] in my paper [2]. In this paper, I shall present more detailed theoretical simulations to analyze the polarization measurements for the uncooled beam in the recent paper by Benati et al. [1]. (I explained in Ref. [2] that the effects of the synchrotron tune modulation on the spin precessions for the cooled beam in Ref. [1] were negligible, and the data in Ref. [1] for the cooled beam could be fitted using a monochromatic beam). The collaboration kindly sent me datafiles of the polarization measurements for the various data points in the resonance dip for the uncooled beam in Fig. 22 in Benati et al. [1]. The (frequency, polarization) values are displayed in Table 1. (Note that 'polarization' will always mean 'normalized polarization' below.) A graph of the data is plotted in Fig. 1.

I was able to fit the data using my own tracking simulations. However, to do so I had to understand the experimental procedure of the measurements, because there were some significant details I had not understood from a reading of [1]. I thank the collaboration for explaining the experimental procedure to me. The following details are significant:

- In response to a query about the contents of some of the datafiles, the collaboration kindly sent me updated files with improved normalization; it is these values which are tabulated in Table 1. The difference with the values plotted in Fig. 22 in Benati et al. [1] is too small to discern visually. I thank the collaboration for responding courteously to my query. *N.B.*: The revised normalizations apply only to the data in Figs. 21 and 22 of Ref. [1]. The term 'data' will always mean 'revised data' for the above cases. I shall also present fits to the data in Figs. 12, 16 and 17 of Ref. [1]; in those cases the data are the same as in Ref. [1].
- It is stated in Ref. [1] that the rf solenoid was ramped linearly to full strength in 200 ms, and that the measured polarization depended on the ramp rate. I confirmed this in my simulations.
- I found that a single value for the resonance center would not fit all the points. The center of the resonance is given in Ref. [1] at 871 434 Hz. However, the two data points at 871 432 Hz and 871 436 Hz, indicated by the arrows in Fig. 1, which should be equidistant from the center of the resonance, do *not* have equal polarizations. I found that some points were fitted by setting the resonant frequency to 871 434.0 Hz and the rest using 871 434.4 Hz. (It is commented in Ref. [1] that the points do not all seem to correspond to the same resonance location; see below.)
- I ran tracking simulations using resonance centers of $f_{\text{res}} = 871\,434.0$ Hz and 871 434.4 Hz. Even so, I was unable to fit all the points, viz. the three leftmost and the rightmost point in Fig. 22 in Ref. [1]. See Fig. 2, to be explained below. My simulation results were sufficiently precise that I realized something had to be different about the experimental parameter settings when measuring these four points; they do *not* belong on the same resonance curve as the rest. However, at this stage it is impossible to offer a definitive reason why I offer my hypothesis below; see Fig. 3, which I shall explain below.
- I shall also fit the data in Figs. 12, 16, 17 and 21 in Ref. [1], and will discuss them below.

The structure of this paper is as follows. Section 2 describes general properties of my fitting procedure. Section 3 describes

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Table 1
Frequency and polarization values published in Fig. 22 in Ref. [1]. The run numbers of the data acquisition are also tabulated. Note that there was no Run 92.

Freq. (Hz)	P	ΔP	Run #
871 412.0	0.93549	0.0018270	83
871 422.0	0.85472	0.0018532	84
871 327.0	0.72391	0.0017741	87
871 432.0	0.43449	0.0018619	86
871 434.0	0.0036147	0.0019661	91
871 435.0	0.11855	0.0018988	88
871 436.0	0.28409	0.0019772	89
871 437.0	0.52834	0.0030428	93
871 439.0	0.64286	0.0020189	90
871 442.0	0.78982	0.0018351	85
871 452.0	0.93168	0.0017655	82

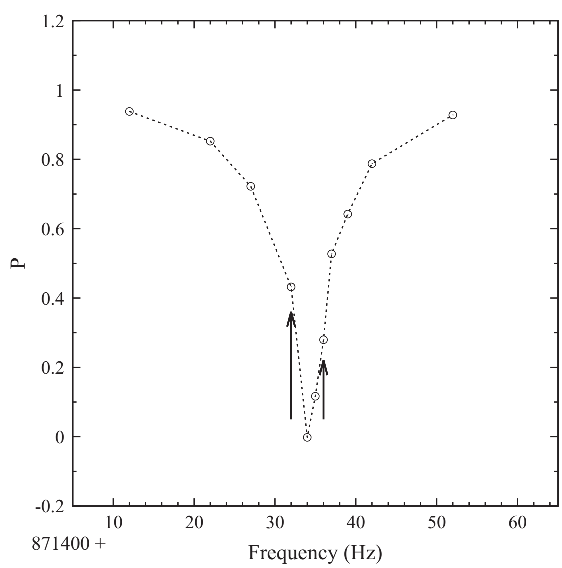

Fig. 1. Data points published in Fig. 22 in Ref. [1]. The numerical values are given in Table 1. The dotted line is just to guide the eye. The arrows indicate the points at frequencies of 871 432 Hz and 871 436 Hz.

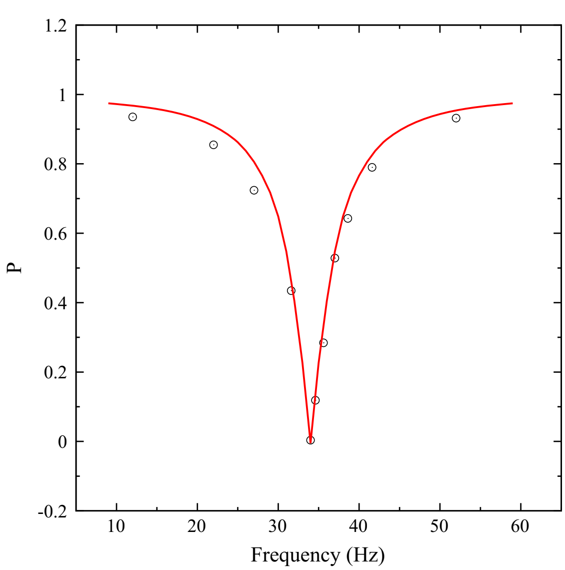

Fig. 2. Plot of data points tabulated in Table 3, using 'effective frequencies' for some data points, as explained in the text. The solid curve is the output of tracking simulations using a resonant frequency of 871 434.0 Hz. The three leftmost points, and also the rightmost point, are not fitted by the curve; this will be explained in the text.

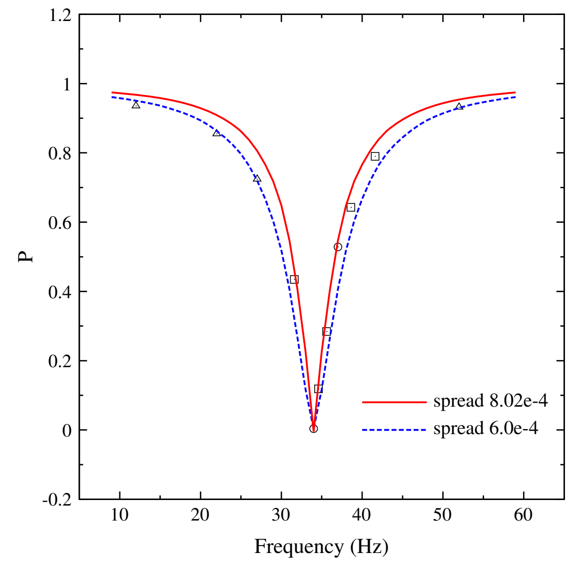

Fig. 3. Plot of data points tabulated in Table 3, using 'effective frequencies' for some data points, as explained in the text. The key for the data points is explained in Table 3. The solid and dashed curves are the outputs of tracking simulations using r.m.s. relative momentum spreads of $\sigma_p = 8.02 \times 10^{-4}$ (solid curve) and $\sigma_p = 6.0 \times 10^{-4}$ (dashed curve).

some corrections to my recent paper [2]. Section 4 presents some remarks on the use of various distributions of the particle orbits to fit the data. Section 5 presents my tracking simulations for the resonance dip of the uncooled beam in Fig. 22 in Ref. [1]. Section 6 presents a comparison with some analytical formulas I derived in Ref. [2]. Section 7 presents my tracking simulations for the data in Figs. 12, 16, 17 and 21 in Ref. [1]. Section 8 concludes.

2. Fits to data

I shall present my detailed investigations later. To summarize:

- Of the eleven points displayed in Fig. 22 in Ref. [1], five were fitted with resonant frequency of $f_{\rm res} = 871\,434.4$ Hz and six were fitted with resonant frequency of 871 434.0 Hz.
- I employed an rf solenoid 'resonance strength' of $\varepsilon_{\rm FWHM} = 2.66 \times 10^{-5}$, as given in Ref. [1]. The rf solenoid field amplitude was ramped linearly to full strength in a time $t_{\rm ramp} = 0.2$ s. It was essential to include this ramp in my simulations to obtain a quantitative fit to the data.
- All of my tracking simulations were computed using a Gaussian distribution of the particle orbits. I employed an r.m.s. relative momentum spread of $\sigma_p = 8.02 \times 10^{-4}$, which is the value stated in Ref. [1] for the uncooled beam. The initial value of the synchrotron oscillation phase was distributed uniformly in $[0, 2\pi)$.
- However, there were four points which I could not fit with the above simulation parameters. These were the three leftmost points and the rightmost point in Fig. 22 in Ref. [1]. The results of my tracking simulations were sufficiently precise that I ruled out statistical fluctuations, even though my numerical work consisted of Monte Carlo simulations, and the data were themselves statistical samples. Something must have been different about the experimental settings when measuring these four points. I was able to fit these four points using a smaller r.m.s. relative momentum spread of $\sigma_p = 6.0 \times 10^{-4}$. This is simply a hypothesis; it is a possible but not a conclusive explanation of the data; there were most likely multiple causes.
- I therefore compiled the data into a 'common set' where all the points were based on a resonance center of 871 434.0 Hz. I did