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CONFERENCE PROCEEDING

Analysis of the differential nonlinearity for the velocity driving systems in Mössbauer spectrometers using thin α-Fe reference absorber

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Abstract

A simple method for estimation of the differential nonlinearity for the velocity driving systems in Mössbauer spectrometers using the reference absorber of the thin α-Fe foil is presented. This method was applied for testing the differential nonlinearity of velocity in Ranger Electronics, Wissel and SM-2201 spectrometers. The results demonstrated a significant differential nonlinearity in the case of out-of-tune velocity driving system while adjusted spectrometers showed comparable differential nonlinearity below 0.4%.

Keywords Mössbauer spectroscopy · Velocity driving system · Differential nonlinearity

1 Introduction

The differential nonlinearity (DNL) is one of the important characteristics of the velocity driving system in Mössbauer spectrometers operated in the constant acceleration mode with linear velocity reference signals such as, e.g., triangular or saw-tooth. Recently, a method for estimation of DNL using α-Fe foil with a thickness of 25 μm was suggested by Grandjean and Long [1] as the best Protocol. The authors fitted their folded Mössbauer spectrum of α-Fe foil with six independent single Lorentzian peaks and compared the peak positions

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with very old data obtained by Violet and Pipkorn [2] using Livermore constant velocity Mössbauer spectrometer for the standard reference material 1541 α-Fe foil from the National Bureau of Standards. However, in general, this is not the best protocol by the following reasons: (i) the velocity errors and DNL for two velocity directions in the case of triangular velocity reference signal may be different, therefore, the folded spectrum will accumulate the errors and DNLs from two parts of the velocity; (ii) although the ideal α-Fe with a cubic structure should have zero isomer shift (δ) and zero quadrupole shift (ε), real α-Fe foils demonstrate slight deviations from zero for δ and ε in the cases of precise measurements, these deviations are related to the foil preparations; therefore, the measurements should be carried out using the same α-Fe foil; (iii) a comparison of the peak positions determined from the fits using a magnetic sextet with physical links between the ^{57}Fe nuclear transitions and six independent single peaks gives more reliable DNL of the velocity than that suggested in [1]; (iv) the constant velocity Mössbauer spectrometers have their own velocity errors, therefore, the measurements should be done using the same Mössbauer spectrometer. Another simple method for the DNL estimation using the thin reference absorbers, in particular, the α-Fe foil, was considered at the same time in [3]. In the present work we consider this simple method and its application for the DNL analysis in several different Mössbauer spectrometers.

2 Experimental

A reference absorber of α-Fe foil with a thickness of 7 μm was used for all measurements at room temperature. The Mössbauer spectra used for comparison were measured in the period of 2017–2022 using different spectrometers, namely Ranger Electronics and Wissel operating with the triangular velocity reference signal with recording the two mirror spectra in 256 channels for each, and SM-2201 operating with the saw-tooth velocity reference signal with discretization of 2^{12} and recording the spectra in 4096 channels (later these spectra can be converted into the 2048-, 1024-, 512- or 256-channel spectra by consequent summation of 2, 4, 8 or 16 neighboring channels, respectively). All measurements were done in transmission geometry with moving source (Ranger and Wissel) and with moving absorber (SM-2201). The measured spectra were fitted using the UNIVEM-MS program with Lorentzian line shape within two models: (i) one magnetic sextet and (ii) six independent singlets. The obtained parameters were δ, ε, magnetic hyperfine field H_{eff}, line widths Γ, and peak positions in channels. The differential spectra were used for the analysis of the fitting quality and the quality of the velocity driving system. The two mirror spectra were fitted separately with accounting for distortion of the base line which was well fitted by the approximation as a parabolic distortion if this was needed. The left mirror spectrum ("direct" velocity, i.e., from $-V$ to $+V$) was marked as "d" while the right mirror spectrum ("reverse" velocity, i.e., from $+V$ to $-V$) was indicated as "r". The values of δ are given with respect to α-Fe at 295 K.

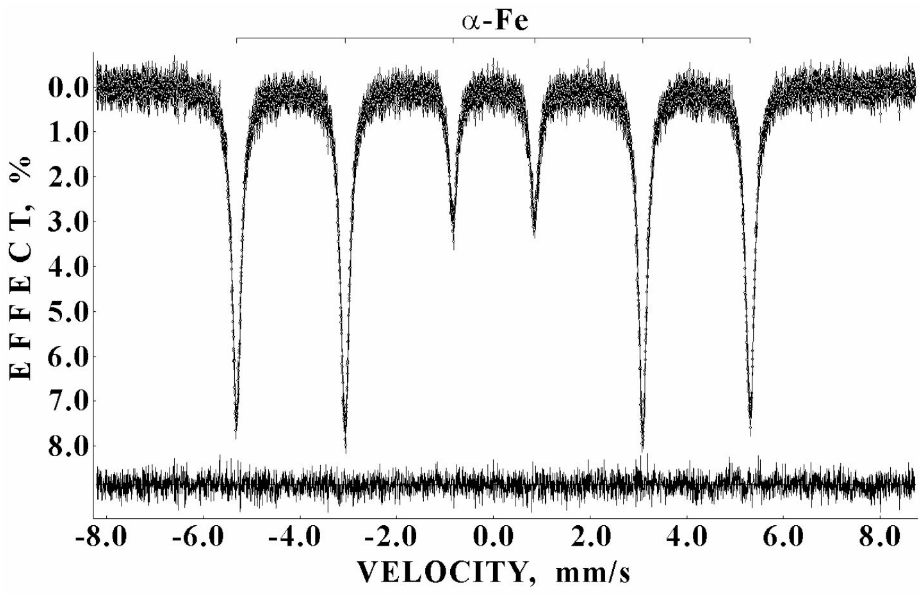

Fig. 1 Mössbauer spectrum of the reference absorber of the 7 μm α-Fe foil

3 Results and discussion

The Mössbauer spectrum of the reference absorber of 7 μm α-Fe foil measured using SM-2201 in 4096 channels is shown in Fig. 1. The Mössbauer parameters obtained from the fit using a magnetic sextet are: $\delta = 0.005 \pm 0.004$ mm/s, $\varepsilon = -0.011 \pm 0.004$ mm/s, $H_{eff} = 329.9 \pm 0.5$ kOe (value for calibration), and narrow Lorentzian line width for the 1st and the 6th, the 2nd and the 5th, and the 3rd and the 4th peaks in sextet: $\Gamma_{1,6} = 0.225 \pm 0.008$ mm/s, $\Gamma_{2,5} = 0.220 \pm 0.008$ mm/s and $\Gamma_{3,4} = 0.207 \pm 0.008$ mm/s. The larger intensity of the second and fifth peaks is related to the texture effect originated from the shape anisotropy of the thin ferromagnetic foil.

The simple method for analysis of the DNL suggested in [3] considers the measurement of the thin reference absorber, in this case, the 7 μm α-Fe foil and fit the spectrum in two ways: (i) with one magnetic sextet using the Hamiltonian perturbation of the first order with six peak positions determined by the hyperfine interactions and (ii) with six independent singlets as geometrical fit of the sextet (see Fig. 2). Then the distances between chosen peak positions determined for both fits can be used for the estimations of DNL for chosen velocity ranges (in channels) in the spectra: $A_{m,n}$ and $B_{m,n}$, where m and n = 1–6 as shown in Fig. 2.

Then the DNL can be determined for the corresponding velocity ranges by the ratio: $|A_{m,n} - B_{m,n}|/A_{m,n}$ in the arbitrary units (ar.un.) or in %. The results for DNL estimations for the spectrum shown in Fig. 2 are presented in Table 1.

The selected examples of the direct spectra measurements using Ranger Electronics and Wissel are shown in Figs. 3 and 4 and results are presented in Tables 2 and 3, respectively.

The number of channels in the spectrum have not a significant meaning in this method, however, the DNL estimations may slightly vary. For example, a comparison of the DNL estimation for the 7 μm α-Fe foil Mössbauer spectrum measured in 4096 channels using

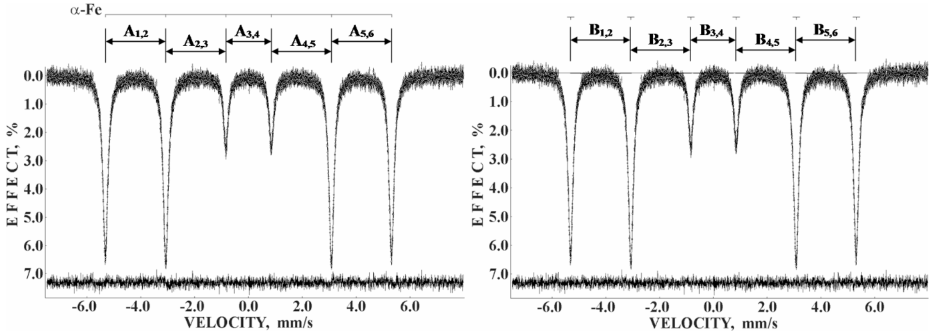

Fig. 2 Mössbauer spectrum of the 7 μm α-Fe foil measured using SM-2201 spectrometer with two different fits. $A_{m,n}$ and $B_{m,n}$ are the chosen velocity ranges for estimation of the differential nonlinearity of the velocity scale. The differential spectra are shown at the bottom

Table 1 Estimation of the differential nonlinearity for the velocity ranges in the Mössbauer spectrum measured with SM-2201 spectrometer and shown in Fig. 2

Velocity ranges	1–2	2–3	3–4	4–5	5–6
DNL, ar.un.	0.000258	0.000333	0.000417	0.001147	0.000521

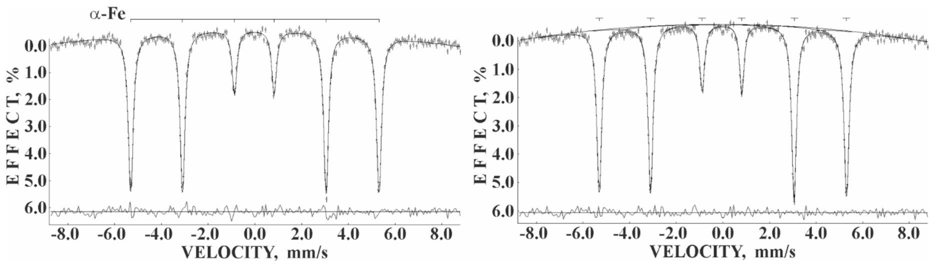

Fig. 3 Direct Mössbauer spectrum of the 7 μm α-Fe foil measured using Ranger Electronics spectrometer with two different fits and accounting for parabolic distortion. The differential spectra are shown at the bottom

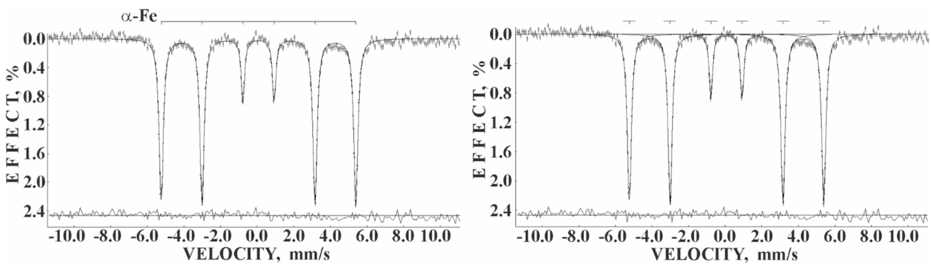

Fig. 4 Direct Mössbauer spectrum of the 7 μm α-Fe foil measured using Wissel spectrometer with two different fits. The differential spectra are shown at the bottom

Table 2 Estimation of the differential nonlinearity for the velocity ranges in the direct Mössbauer spectrum measured using Ranger Electronics spectrometer and shown in Fig. 3

Velocity ranges	1–2	2–3	3–4	4–5	5–6
DNL, ar.un.	0.000589	0.000592	0.000392	0.001777	0.000595

Table 3 Estimation of the differential nonlinearity for the velocity ranges in the direct Mössbauer spectrum measured using Wissel spectrometer and shown in Fig. 4

Velocity ranges	1–2	2–3	3–4	4–5	5–6
DNL, ar.un.	0.000394	0.000788	0.002088	0.003152	0.001182

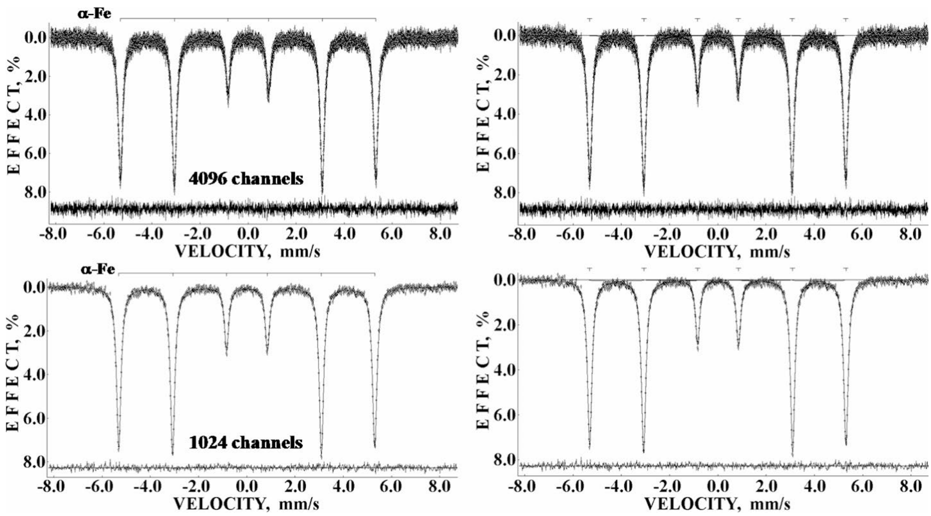

Fig. 5 Mössbauer spectrum of the 7 μm α-Fe foil measured using SM-2201 spectrometer in 4096 channels and additionally converted into the 1024-channel spectrum fitted using two different models. The differential spectra are shown at the bottom

Table 4 Estimation of the differential nonlinearity for the velocity ranges in the same Mössbauer spectrum measured using SM-2201 spectrometer and presented in 4096 and in 1024 channels as shown in Fig. 5

Velocity ranges	1–2	2–3	3–4	4–5	5–6
4096 channels, DNL, ar.un.	0.000394	0.000788	0.002088	0.003152	0.001182
1024 channels, DNL, ar.un.	0.000295	0.000370	0.000392	0.001184	0.000521

SM-2201 spectrometer and additionally converted into the 1024-channel spectrum are shown in Fig. 5 and the estimations of the DNL are listed in Table 4. Some differences in the DNL estimations for 4096- and 1024-channel spectra may be related to the higher precision of the determination of the peak positions with a higher velocity resolution and, therefore, to the lager differences between $A_{m,n}$ and $B_{m,n}$. However, the DNL is an individual characteristic of each velocity driving system in Mössbauer spectrometer and should be determined for the real number of channels as determined by discretization of the velocity reference signal.

In the case, when the velocity driving system is out-of-tune, significant misfits can be clearly seen in the differential spectrum after fitting with one magnetic sextet indicating that

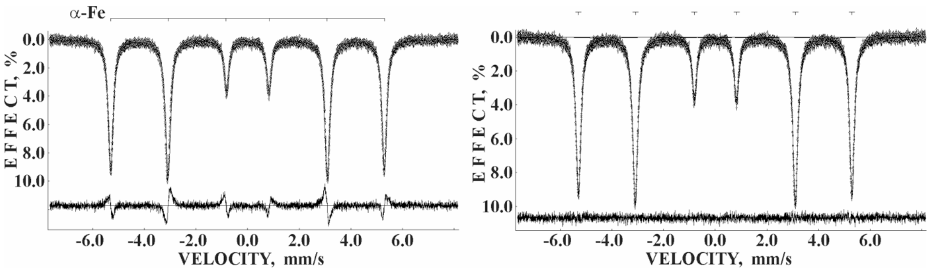

Fig. 6 Mössbauer spectrum of the 7 µm α-Fe foil measured using SM-2201 spectrometer with out-of-tune velocity driving system in 4096 channels with two different fits. The differential spectra are shown at the bottom

Table 5 Estimation of the differential nonlinearity for the velocity ranges in the Mössbauer spectrum measured using SM-2201 spectrometer with out-of-tune velocity driving system shown in Fig. 6

Velocity ranges	1–2	2–3	3–4	4–5	5–6
DNL, a.u.	0.016205	0.025278	0.034371	0.0208	0.015504

the registered energies of the ^{57}Fe nuclear transitions were shifted in the spectrum due to the velocity nonlinearity and other velocity errors as demonstrated in Fig. 6 with the DNL estimations presented in Table 5.

A comparison of all considered estimations of the DNL using the Mössbauer spectra of the same 7 µm α-Fe foil measured with Ranger Electronics, Wissel and SM-2201 spectrometers including direct and reverse parts of the two mirror spectra measured in 256 channels as well as the spectra measured in 4096 channels and additionally converted into the 2048-, 1024- and 256-channel spectra is presented in the plot shown in Fig. 7. This comparison indicates that the DNL is not the same for the considered velocity ranges for all spectrometers. In the case of out-of-tune velocity driving system, the DNL has the largest values which substantially exceed all other estimations of the DNL. Some differences can be observed for the DNL estimations for the direct and reverse parts of the two mirror Mössbauer spectra measured with spectrometers operated with the triangular velocity reference signal. In the case of Wissel spectrometer, these differences are not so big while those for Ranger Electronics spectrometer are much more pronounced. A comparison of the DNL estimations for the same Mössbauer spectrum converted in different numbers of channels demonstrates some differences which may be a result of the difference in the precision of determination of the peak positions. For example, in the 4096-channel spectrum the peak position can be determined with accuracy of 16 times higher than that in the 256-channel spectrum. Therefore, this conversion can average some tiny differences in the peak position. In general, the majority of estimated DNL values for the considered velocity ranges for three Mössbauer spectrometers with adjusted velocity driving systems are below 0.004 ar. un. or ≤ 0.4%.

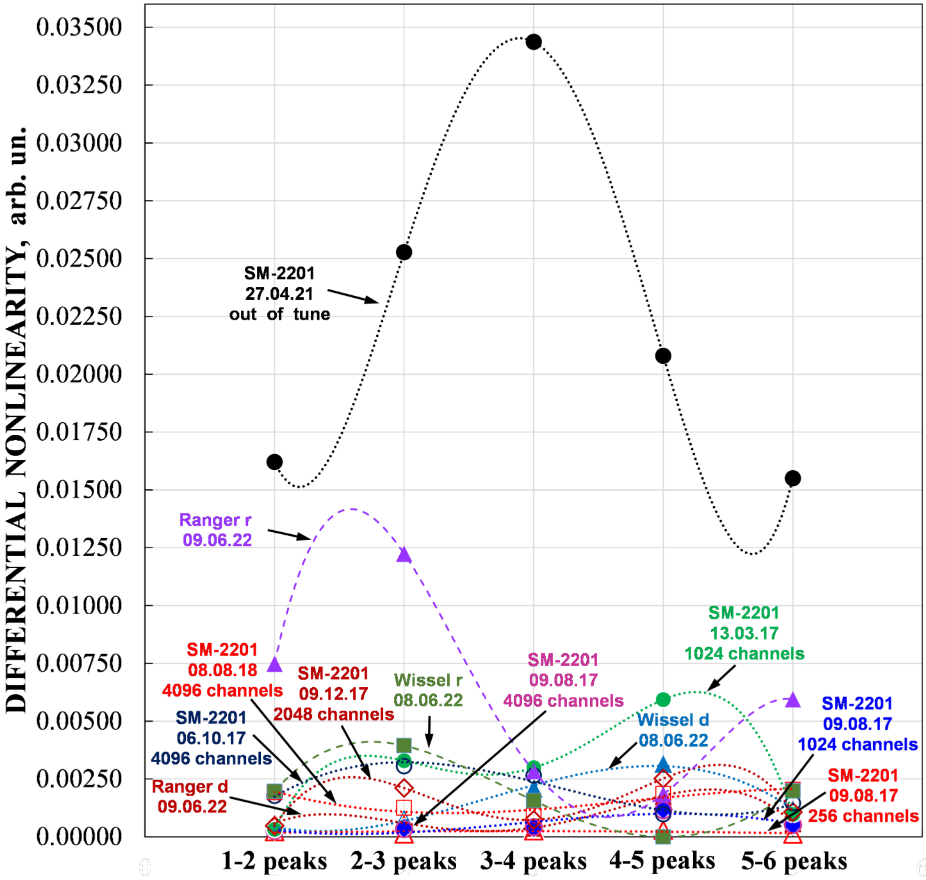

Fig. 7 Comparison of the estimated values of the differential nonlinearity for different Mössbauer spectrometers with spectra measurement at different time for adjusted and out-of-tune velocity driving systems, for the direct (d) and reverse (r) two mirror spectra as well as for different numbers of channels in the spectrum. The dashed connecting lines are the polynomial trends

4 Conclusion

A simple method for estimation of the differential nonlinearity of the velocity scale in any Mössbauer spectrometer operating in the constant acceleration mode with triangular and saw-tooth velocity reference signals using a thin reference absorber of α-Fe foil was suggested. This method was tested for three spectrometers such as Ranger Electronics, Wissel and SM-2201 using the same 7 μm α-Fe foil as the reference absorber. This method allowed one to use the same spectrometer and one α-Fe foil for the DNL estimation for chosen velocity ranges which exclude the effect of different velocity errors in the cases of comparison of the Mössbauer spectra measured with two different spectrometers and possible differences in the α-Fe foil preparations. The results of the DNL testing show the following:

– the out-of-tune velocity driving system demonstrates substantially high values of the DNL for chosen velocity ranges;

- the values of DNL for different velocity ranges are slightly different;
- in the case of triangular velocity reference signal, the values of the DNL for the same velocity ranges may be different for the direct and reverse velocities which indicate the different velocity errors for the direct and reverse velocity ranges that may be important for the control of the folded spectrum quality;
- the number of channels in the spectrum has no substantial meaning for the DNL estimations, however, in the case of the spectrum conversion from the larger number of channels to the smaller one, the DNL values may be very slightly decreased due to a decrease in the precision of determination of the peak positions.

The results of this test for the DNL estimations demonstrated that for different adjusted spectrometers and for the chosen velocity ranges the values of DNL were below 0.004 ar.un. or ≤0.4% mainly.

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Author contributions M.I.O., E.K., Z.H. and V.A.S. carried out experiments; M.I.O. wrote the main manuscript text; all authors discussed the results and reviewed the manuscript.

Data Availability All data can be obtained from the corresponding author under request.

Declarations

Competing interests The authors declare no competing interests.

Ethical approval Not applicable.

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