HYSITS: A MATLAB Code to Process Vibrating Sample Magnetometer Data (Hysteresis Loop)

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Abstract. Vibrating-sample magnetometer (VSM) is a magnetic measurement method by observing magnetic moment (M) which is a response of applying ascending and descending magnetic field (H) to the material. The data of this ascending and descending magnetic field will form a kind of loop called hysteresis loop. The hysteresis curve of each material will be different for each kind, so that this curve can be used to evaluate type and domain of magnetic mineral. This paper introduces HYSITS, a MATLAB code for analysing the magnetic hysteresis curve. We aim to provide an easy-use program, such as the feature to adjust smoothing span and increment parameter. With that the hysteresis curve analysis can be done effectively. The optimal result of the parameters adjustment can be seen from the smoothing span 10 for increment values 0.001 and 0.002 on the graph. This MATLAB code will generate 3 plots, which are hysteresis curve (magnetic moment vs. magnetic field), difference of ascending and descending magnetic moment (ΔM vs. H), and the 1st derivative of ΔM vs. H. Although HYSITS has several features that distinguishes it from its non-MATLAB predecessors, HYSITS still needs improvements so that it can be more reliable for research about magnetic hysteresis.

1. Introduction
Rock magnetism has been studied for various scope, mainly for environmental studies[1–8]. There are several methods used to study rock magnetism, one of which is vibrating sample magnetometer (VSM). It is one of the most successful implementations of magnetometer [9]

A sample is exposed to a constant external magnetic field while vibrated vertically perpendicular with respect to the direction of the external magnetic field. The exposed sample is magnetized, introduces perturbation in the magnetic field which then measured by the magnetometer. The applied external field H is then varied, starting from zero magnetic field (H=0) approaches +Hmax (ascending 1), then decayed to zero till approaches -Hmax (descending), and finally rise up again through zero approaches +Hmax (ascending 2). The data will form a hysteresis loop which then can be used for determining magnetic domain type [9–12]. Figure 1 shows some example of magnetic domain type behaviour in hysteresis loop. The determination shown by Tauxe [10,11] is done by observing the three plots, which each magnetic domain type has its curve characteristic behavioural.

One of the existed tools for displaying magnetic hysteresis curve is MagePlot[13], which is an online web-based plotting application. This application generates three plots, including the hysteresis curve, its 1st derivative and 2nd derivative of each ascending and descending curve. It does not
provide to plot the $\Delta M$ which can be helpful to interpret the domain type. Also, it does not provide smoothing option, which causes the derivative curves displayed is not comfortable to be interpreted further.

Due to that reason, we are motivated to create a program which can fulfil the needs in interpreting magnetic hysteresis curve. It is in the form of MATLAB code named HYSITS, which can be easily executable. It is an offline program, so it does not depend on internet connection availability and has more flexible handle in adjusting the displayed plot. It will provide plotting VSM data in three kinds of plots such as in Fig. 1.

Figure 1. Hysteresis curve (top), $\Delta M$ curve (middle), and 1st derivative of $\Delta M$ (bottom). From left to right: hematite, SD (single domain) magnetite, hematite plus magnetite, and SD plus SP (superparamagnetic) magnetite [10]

2. Method
Hysteresis curve will be analyzed by observing the distance or difference between descending and ascending. It will need three plots, including hysteresis curve ($M$ vs. $H$), the difference between descending and ascending ($\Delta M$ vs. $H$), and the 1st derivative of $\Delta M$ ($d(\Delta M)/dH$ vs. $H$). The flowchart to obtain those plots is shown in Fig. 2.

In this paper, we will show an illustrative usage of HYSITS using an example data of magnetic hysteresis loop curve. The data to be inputted into this MATLAB code consist of 2 columns and 2 parts. The 1st part is the 1st row of the data file, consists of sample name (at the 1st column) and sample weight (at the 2nd column). The 2nd part is the 2nd row until the end of the data file, consists of magnetic field ($H$) at the 1st column and magnetization ($M$) at the 2nd column. A clear description of data structure is shown in the Fig. 3.

The VSM data consist of three steps, which are ascending 1 ($asc_1$), descending ($dese$), and ascending 2 ($asc_2$), but the data that will be used for the interpretation is only the last two steps (dese and $asc_2$; for the simplicity we will call $asc_2$ by only $asc$ because we won’t use the $asc_1$). Those three steps are all inputted in the data file without any differentiator or delimiter (see Fig. 3). This
MATLAB code will distinguish those three steps by identifying the maximum ($H_{\text{max}}$) and minimum ($H_{\text{min}}$) magnetic field. The desc is the data from $H_{\text{max}}$ till $H_{\text{min}}$, while asc is from $H_{\text{min}}$ till the end of the data.

Beside defining the desc and asc, HYSITS also omitting the “twin data”, that is a magnetization (M) value that was recorded more than once in the same magnetic field (H) in the same step (asc, desc, or asc). This twin data needs to be omitted in order to be not confused in the next step of the code (interpolation). Interpolation needs to be done to obtain the difference between desc and asc ($\Delta M$). Interpolation is done by using MATLAB internal function “interp1” which is interpolating between 2 points by using linear interpolation.

### 3. Results

The output of HYSITS for the data example is shown in Fig. 4-6. Each figure consists of three plots as described at the Methodology. The hysteresis curve plot is shown in its original data value, while $\Delta M$ and its 1st derivative is shown in normalized value (divided by the highest value).

We are showing some variation of parameters used in this MATLAB code to show the significance of those two parameters. The increment is varied by two values, which are 0.001 and 0.002. The smoothing span is varied by three values, which are 1, 10, and 20.

Generally, the highest value of smoothing span will generate a smoother curve. When using smoothing span 1, there was not much difference between increment 0.001 and 0.002 (Fig. 4). In the smoothing span 10 (Fig. 5), there was significant change between those two increments. When using more detailed increment (value of 0.001; Fig. 5a), the curve shows many spikes compared to less detailed increment (value of 0.002; Fig. 5b). This also occurred for the higher smoothing span with value of 20 (Fig. 6).
4. Discussion
One of the most important steps in HYSITS’ algorithm is data smoothing. Data smoothing is commonly used in data analysis, especially regarding geophysics [14–16]. In order to do VSM data smoothing in HYSITS, the smoothing span needs to be adjusted beforehand. The adjustment of smoothing span needs to be done to get a smoother curve, so that the noise effect can be reduced and the curve is easier to be interpreted without aliasing the real condition of the data. As has been described in the Methods section, there was not much difference between the two increment variations when the smoothing span is applied with the lowest value (Fig. 4). But as the smoothing span was increased (Fig. 5-6), there was some difference. The higher increment (with value of 0.001) has more spike compared to the increment 0.002. More detailed curve (caused by higher value of increment) can cause more disturbance that causing it to be harder to interpret. But even though it has such differences, the main thing about interpreting hysteresis curve is observing the trend of the gradient. It means that such differences in Fig. 4-6 does not cause a significant effect in determining magnetic domain of a rock sample.

Figure 4. Example data using smoothing span 1 and variation of increment (a) 0.001 and (b) 0.002
Figure 5. Example data using smoothing span 10 and variation of increment (a) 0.001 and (b) 0.002

Figure 6. Example data using smoothing span 20 and variation of increment (a) 0.001 and (b) 0.002
HYSITS able to process VSM data with only setting three variables: file directory, smoothing span, and increment for interpolation. While MagePlot [13] needs to set ‘more’ things (compared to HYSITS). HYSITS has a different method for interpretation compared to MagePlot. The aim of HYSITS is enhancing the data by doing smoothing and interpolation in order to get the $\Delta M$ and its 1st derivative for interpretation (shortly, the interpretation would be based on the $\Delta M$ and its 1st derivative [10,11]). While MagePlot aim to plot the data by showing hysteresis curve and its 1st and 2nd derivative for the interpretation. It means that the interpretation of MagePlot’s output will be done by observing each ascending and descending curve, while HYSITS’s output will be interpreted by observing the difference between ascending and descending curve. At this state, HYSITS does complete features for data correction, such as in MagePlot. But we plan to keep improving this program, so that HYSITS can be more reliable for research about magnetic hysteresis.

5. Conclusion
Hysteresis curve contains many information that can be shown more by processing it first. The hysteresis loop data needs to be sorted, smoothed, and interpolated in order to obtain the $\Delta M$ which represents the magnetic domain type. Its 1st derivative also needed to improve the determination. HYSITS provide those features in the form of MATLAB code which can be easily executable. There are two parameters that need to be adjusted by user, which are smoothing span and increment (for interpolation). Those parameters can be subjectively adjusted by user to get a better figure for a better interpretation of rock magnetic domain.

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Appendix – HYSITS MATLAB code

cle, clear all, close all

%The following three lines need to be adjusted by user
FileName = 'D:\AC\data_example_vsm.dat'; %Directory file
Param.SS = 20; %Smoothing span
Param.incr = 0.001; %Increment of H for interpolation

%Reading data
DataRead = char(fileread(FileName));
DataRead = strsplit(DataRead,{'	','
'});
Data.SampleName = DataRead(1);
if length(Data.SampleName)>30
    Data.SampleName = Data.SampleName(1:30);
end
DataRead(1) = {'0'};
DataRead = str2double(DataRead);
Data.w = DataRead(2);
Data.H = DataRead(3:2:end)';
Data.M = DataRead(4:2:end)'/Data.w;
[-,Data.ind_min] = min(Data.H);
[-,Data.ind_max] = max(Data.H);

%Sorting
Raw.H_desc = Data.H(Data.ind_max:Data.ind_min);
Raw.M_desc = Data.M(Data.ind_max:Data.ind_min);
[Raw.H_desc,Raw.uH_desc] = unique(Raw.H_desc);
Raw.M_desc = Raw.M_desc(Raw.uH_desc,:);
Raw.H_asc = Data.H(Data.ind_min:end);
Raw.M_asc = Data.M(Data.ind_min:end);
[Raw.H_asc,Raw.uH_asc] = unique(Raw.H_asc);
Raw.M_asc = Raw.M_asc(Raw.uH_asc,:);

%Interpolation and Smoothing
Interp.H2_desc = [Raw.H_desc(1):Param.incr:Raw.H_desc(end)'];
Interp.M2_desc = interp1(Raw.H_desc,Raw.M_desc,Interp.H2_desc);
Interp.M2_desc = smooth(Interp.M2_desc,Param.SS);
Interp.H2_asc = [Raw.H_asc(1):Param.incr:Raw.H_asc(end)'];
Interp.M2_asc = interp1(Raw.H_asc,Raw.M_asc,Interp.H2_asc);
Interp.M2_asc = smooth(Interp.M2_asc,Param.SS);

%Calculating delta_M and its 1st derivative
Cal.delta_m = (Interp.M2_desc-Interp.M2_asc);
Cal.deriv_1 = diff(Cal.delta_m)/Param.incr;

%Plots
figure
set(gca,'Units','Normalized','OuterPosition',[0 0.3125 0.95 0.62])
subplot(1,3,1),
plot(Interp.H2_desc,Interp.M2_desc,Interp.H2_asc,Interp.M2_asc,'b')
hold on,
line(xlim, [0 0],'Color','k');
line([0 0], ylim,'Color','k');
xlabel('H (T)'),ylabel('M (emu/g)')
title('Hysterisis Curve')
subplot(1,3,2),
plot(Interp.H2_asc,Cal.delta_m/max(Cal.delta_m))
xlim([0 max(xlim)])
hold on
line(xlim, [0 0], 'Color', 'k');
line([0 0], ylim, 'Color', 'k');
xlabel('H (T)'), ylabel('delta M (emu/g) (Normalized)')
title ('Delta M')
subplot(1,3,3),
plot(Interp.H2_asc(1:end-1),-Cal.deriv_1/max(-Cal.deriv_1))
xlim([0 max(xlim)])
hold on
line(xlim, [0 0], 'Color', 'k');
line([0 0], ylim, 'Color', 'k');
xlabel('H (T)'), ylabel('d(delta M)/d(H) (Normalized)')
title ('1st Derivative of delta M')
suptitle(Data.SampleName)
Param.Annotation = {
    ['[Increment : ' num2str(Param.incr) ']
     [Smoothing span : ' num2str(Param.SS) ']']
};
annotation('textbox',[0.6 0.78 0.4 0.2], 'String', ...
    Param.Annotation, 'FitBoxToText','on', 'FontSize', ...
    8,'LineStyle','none')