Magnetic Concentration Analyzer

MagQuan

Operation and Maintenance Manual

USB-20150416-1

Contents

Safety Information

Please review the following safety warnings to avoid injury and prevent this product or any other related products from getting damaged. To avoid potential hazards, please use this product according to instructions.

Avoid fire or personal injury

Use the appropriate power cord. Please use only the power cord specified by this product and those approved by your country.

Correct connection and disconnection. Before connecting the product with the computer, please ensure whether or not the computer has been booted, and only switch on the power of this product after the computer has been booted. If you want to disconnect the product with the computer, please first disconnect and delete the software before shutting down the product.

Grounding. This product is grounded and connected through the power line. To avoid electrical shock, the grounding wire must be connected to the ground. Before connecting the product with the input and output terminals, please ensure that it has actually been grounded.

Observe all the power of terminals. To avoid fire or electrical shock, please pay attention to power and indications on the product. Before connecting the product, please read the product manual to get a better understanding of the power information.

Power disconnection. For disconnecting the electric supply and for any power connection for the product, please refer to indication to ensure the correct positions. Please do not obstruct the power switch, and ensure that user is able to reach for the power switch at any time.

Please do not operate the product if the cover is left opened. If the cover has been removed, please do not operate this product.

Please do not operate if there is any suspicious malfunctioning. If you suspect that this product has been damaged, please allow qualified maintenance personnel to inspect on it.

Avoid exposed circuitry. In the event of power conductance, please do not touch the exposed connector and component.

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Please do not operate it under a damp status.

Please do not operate it in an environment filled with combustible or explosive gas.

Please maintain the product's surface clean and dry.

Please operate and store in an adequate environment. This equipment is designed to be safe at least under the following conditions:

a) indoor use;

b) altitude up to 2 000 m;

c) temperature 5 °C to 40 °C;

d) maximum relative humidity 80 % for temperatures up to 31 °C decreasing linearly to 50 % relative humidity at 40 °C;

e) MAINS supply voltage fluctuations up to ±10 % of the nominal voltage

Warning! This warning indicates that such operation condition may cause injury or casualty.

Attention! This attention indicates that such operation condition may cause this product or other item to damage.

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Environmental Precautions

In this section, we would provide relevant information on the impacts the product would bring to the environment.

Product Disposal

While recycling the instrument or components, please refer to the following guidelines:

Equipment recycling: The production process of this equipment is compliant to natural recycling and regeneration issues.   If this product is not handled properly in the course of disposal, it might generate harmful substances that may cause environmental or human health hazards.   To avoid such substances from being released to the environment and reduce the use of natural resources, we suggest that you discard this product through a proper recycling system to ensure that most materials can be recycled and reused properly.

Chapter 1 Main Function and Application

Section 1 Function and Design Principles

Currently the instruments used to measure the magnetic concentration are either of vibration sample magnetometer, SQUID magnetometer, or inductively coupled plasma-mass spectrometer. However, these analyzers are very expensive and high maintenance costs. We specifically developed this Magnetic Concentration Analyzer (MagQuan) to measure the magnetic concentration of samples within three minutes. MagQuan is very suitable for material development and quality control.

The analyzer (MagQuan) obtains magnetic concentration of the sample by the measurement of alternative-current (AC) magnetization.

AC magnetic susceptibility of magnetic materials is described below:

Under an external directive-current (DC) magnetic field (H), the direction of magnetic dipoles of a magnetic substance tends to be along the direction of the external magnetic field.

When the magnetic field strength H increases and the magnetic dipole M will also increase as shown by the curve from point 0 towards saturation. Now if the magnetic field strength is reduced to zero, the magnetization will not yet have reached
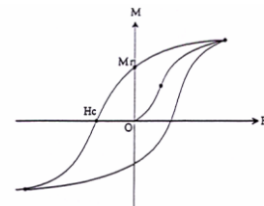
Figure 1 Magnetic Hysteresis loop.

zero, because there is still a remanent magnetic dipole M_r. This is called the residual magnetism or remanence.

When the externally field applied in the opposite direction, the magnetic field strength H_c does M_r reach zero. The magnetizing force which must be applied to null the residual flux density is called a "Coercive Force". When the field is further increased in the reverse direction the material reaches negative saturation point. Increasing the field H back in the positive direction will return M to zero. Notice that the curve does not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path to the saturation point where it with complete the loop. This path is called a Magnetic Hysteresis Loop, shown in Figure 1.

If the external magnetic field is an AC magnetic field with low frequency (generally lower than microwave frequency), the magnetic dipole M oscillates with this AC magnetic field. The oscillation frequency of magnetic dipole is the same as that of the external AC magnetic field, but a phase difference between of the magnetic dipole M and the external AC magnetic field H, as shown in Figure 2.

The external AC magnetic field H in Figure 2(a) can be expressed as $H_0\cos(\omega t)$, the magnetic dipole M can be expressed as $M_0\cos(\omega t - \theta)$, As shown in Figure 2(b), where θ is the phase difference of magnetic dipole with respect to the external magnetic field.
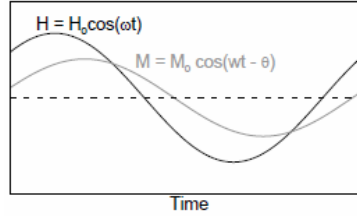
(a)

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(b)

Figure 2 Temporal magnetic dipole M of magnetic material under the applied AC magnetic field H.

The AC magnetic susceptibility χ_{ac} can be expressed as

$$\chi_{ac} = M/H_0 = (M_0/H_0)\cos(\omega t-\theta) = \chi_{ac,\,0} \cos(\omega t-\theta) \qquad (1)$$

MagQuan measures the amplitude of AC magnetic susceptibility $\chi_{ac,0}$ of the magnetic material at a fixed frequency. At low frequencies and low external magnetic field strength, the AC magnetic susceptibility χ_{ac} can be expressed as

$$\chi_{ac,o}(\omega \rightarrow 0, H \rightarrow 0) \approx 0.32 M_0/k_B T \qquad (2)$$

where k_B is the Boltzmann constant, T is the absolute temperature. Thus, the amplitude of AC magnetic susceptibility $\chi_{ac,0}$ is proportional to the magnetic dipole strength M_0 at a fixed temperature. Equation (2) reveals the fact that the $\chi_{ac,0}$ at a low frequency, under low applied magnetic field strength, and at the fixed temperature is equivalent to analyze the magnetic concentration M_0 of magnetic material.

Detailed information of components and features of MagQuan is described in Chapter 3.

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Section 2 Application Example

Immunomagnetic magnetic particle are widely applied in the biomedical researches, such as magnetic resonance contrast agents, drug carriers, hyperthermia agent, cell separation reagents, biological molecules/nucleic acid purification kits, and immunoassay.

When using immunomagnetic particles, we have to confirm the magnetic concentration of immunomagnetic particles in reagent, such as how much amount of particles in terms of Fe concentrations per milliliter in reagent. MagQuan can rapidly quantify the magnetic concentration of immunomagnetic reagents.

Figure 3 Different magnetic concentrations of immune magnetic bead reagent.

For example, one can prepare several 0.1-ml immunomagnetic reagents of various magnetic concentrations, as shown in Figure 3. Using the analyzer to measure the amplitude of the AC magnetic susceptibility of each reagent (results are shown in Figure 4), we get a linear relationship. Therefore, an unknown magnetic concentration
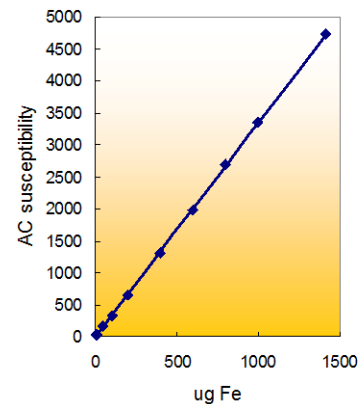
Figure 4 AC susceptibility of immunomagnetic reagent as function of magnetic concentration.

of immunomagnetic reagent can be determined by using

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this analyzer via the linear relationship of Figure 4. The lowest detectable magnetic concentration is 0.05 mg-Fe/ml (= 5 µg Fe) or 0.01 emu/g (= 0.001 emu).

Chapter 2 Introduction of MagQuan

Section 1 Hardware Architecture

The analyzer MagQaun consists of AC signal generating circuit, coil assembly, voltage amplifier circuit, peak detector circuit and DAQ card. The structural diagram of MagQuan is shown in Figure 5.
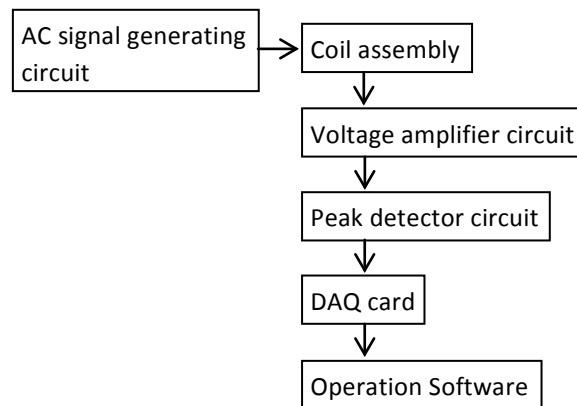
```
┌─────────────────────┐      ┌──────────────────┐
│ AC signal generating│ ───> │ Coil assembly    │
│ circuit             │      └──────────────────┘
└─────────────────────┘               │
                                       ▼
                            ┌──────────────────────┐
                            │ Voltage amplifier circuit │
                            └──────────────────────┘
                                       │
                                       ▼
                            ┌──────────────────────┐
                            │ Peak detector circuit │
                            └──────────────────────┘
                                       │
                                       ▼
                            ┌──────────────┐
                            │ DAQ card     │
                            └──────────────┘
                                       │
                                       ▼
                            ┌──────────────────────┐
                            │ Operation Software    │
                            └──────────────────────┘
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Figure 5 S tructural diagram of MagQuan.

The specifications and functions of all components shown in Figure 5 are described in the following sections.

Section 2 Specifications and Features of Each Component

AC Function Generating Circuit

This circuit generates a frequency of 20 kHz sine wave voltage for driving the current flowing through the exciting coil. The peak-to-peak output voltage of the circuit is 20 volts

Coil Assembly

The coil assembly of MagQuan is divided into two sections. One is the excitation coil for generating AC magnetic field; the other is a Faraday coil for sensing AC magnetic susceptibility signal. The constructions of these two coils are briefly explained as follows:

The sectional diagram of the excitation coil is shown in Figure 6. It is made of ABS material being wound with copper wire around its exterior.

Figure 6 Sectional diagram of the excitation coil.

Figure 7 Sectional diagram of the gradient Faraday coil.

The Faraday coil adopted here belongs to a type of gradient Faraday coil. Its sectional diagram is shown in Figure 7. It features an ABS tubular body wound   around

with copper wire. The tubular body comes in a top and bottom section. Each of them is wound with copper wire in an opposite direction. The working principle of each section of Faraday coil is that a voltage induced with the time-varying magnetic flux, which is generated by magnetized substance under AC magnetic field, through the coil. The induced voltage across Faraday coil is proportional to the product of the frequency of AC magnetic field and AC magnetic susceptibility of substance. Thus, at a given frequency of external magnetic field, the AC magnetic susceptibility of substance can be obtained by measuring the induced voltage across the Faraday coil. The main reason of oppositely directing copper wire is to eliminate as much as possible the induced voltage due to AC magnetic field generated from excitation coil upon the impact of signal output of Faraday coil.

The gradient Faraday coil is directly inserted into the excitation coil to be coaxial with excitation coil. The to-be-detected sample should be placed within the tube on the top section (or the bottom section). The relative positions of excitation coil, gradient Faraday coil, and sample are shown in Figure 8.
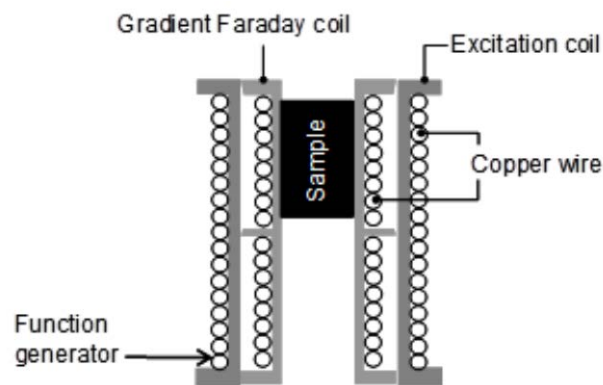
Figure 8 Relative positions of excitation coil, gradient Faraday coil, and sample in the coil assembly of MagQuan.

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Voltage amplifier circuit

The output voltage from the gradient Faraday coil should be guided to this amplifier circuit to increase the voltage signal. The gain is 250.

Peak detector circuit

The frequency of output voltage signal from amplifier circuit is 20 kHz. This signal amplitude is proportional to the amplitude of the ac magnetic susceptibility of the sample. The amplitude of the 20 kHz output signals from voltage amplification circuit is detected with the peak detector circuit.

DAQ card

The DAQ card transmits the signals from the peak detector circuit to the computer through USB terminal for data processing.

Chapter 3 Operation Procedures

Section 1 Operation Program Installation and Equipment Startup

1. Copy MagLysis-Dev1.exe, NIDAQ980f3.exe and LVRTE2011f3std.exe files to a computer. These files are stored in MagQuan Software CD-ROM.

2. Install NI USB-6000 driver "NIDAQ980f3.exe" and LabVIEW Run-Time Engine 2011 "LVRTE2011f3std.exe" (http://www.ni.com/downloads/ni-drivers/).

3. Connect the USB output terminal of MagQuan to the computer. Connect MagQuan to electrical power with a power cord.

4. After connecting MagQuan to your computer, find NI MAX.exe shortcut in your desktop. Double click it.

5. Check if a USB-6000 device is working on with the name is Dev1. If the name is not Dev1, please right click the device and rename it to Dev1. If nothing connects on, please contact NI for further help. (http://www.ni.com)
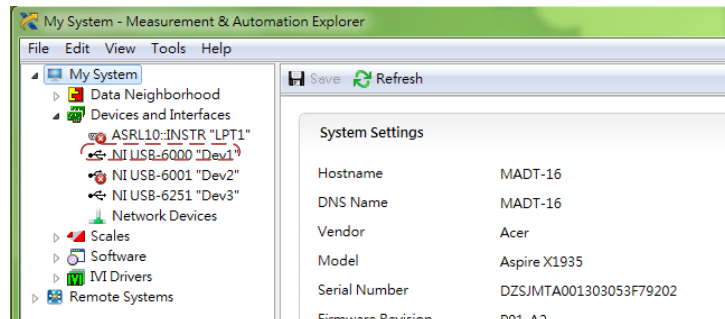
6. Turn on the switch on the rear panel of the analyzer, the switch will be red, and the green LED on the upper left corner of the front panel of the analyzer will light up.

7. Initiate the program MagLysis-Dev1.exe. The following window shows up.
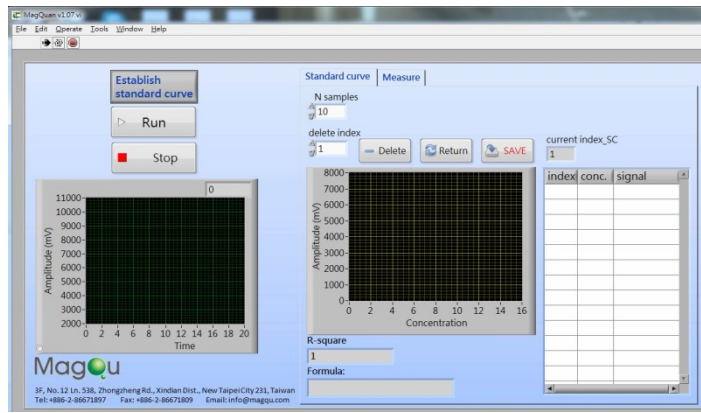
Section 2 Measurement and Analysis of Magnetic Concentration

The measurement procedure is divided into two stages. The first stage is to establish the relationship between the amplitude of the AC magnetic susceptibility $\chi_{ac,0}$ and the magnetic concentration; The second stage is to use this relationship to measure the concentration of the unknown samples. The procedures of each stage are described below respectively.

The first stage: Establish the relationship between the amplitude of the AC magnetic susceptibility $\chi_{ac,0}$ and the magnetic concentration

1. Several samples with known magnetic concentrations are prepared, e.g. 0.1, 1.0, 4.0, 8.0, 14.1 mg-Fe/ml immunomagnetic beads reagent.

2. Take 100 μl sample into the tube respectively, as shown below.
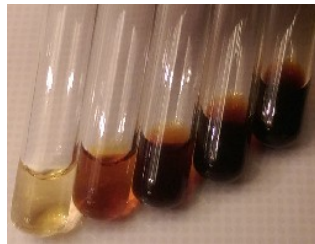
3. Initiate the program MagLysis-Dev1.exe. The following window shows up.
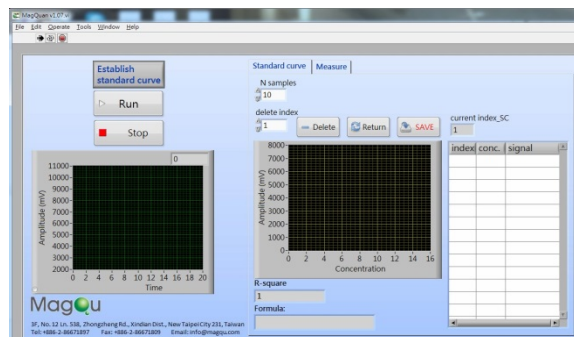
4. Confirm the button shows "Establish standard curve". If not, click the button to switch to "Establish standard curve".

5. Enter the numbers of standard samples in "N samples". For example, we have prepared five standard samples, enter "5".

6. Click the "Run" button, the following window shows up to ask you to select a suitable directory to save the results of the relationship between the amplitude of the AC magnetic susceptibility $\chi_{ac,0}$ and magnetic concentration. For example, the results save in test-curve.txt on desktop. Then, click "OK".
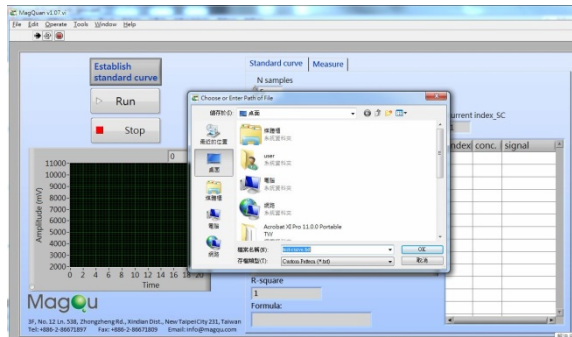
7. After clicking "OK" button of the dialog box as shown above, the following dialog box will appear to ask you to enter the magnetic concentration of the first standard sample. For example, the concentration of the first standard sample is 14.1 mg-Fe/ml, and then key in 14.1.
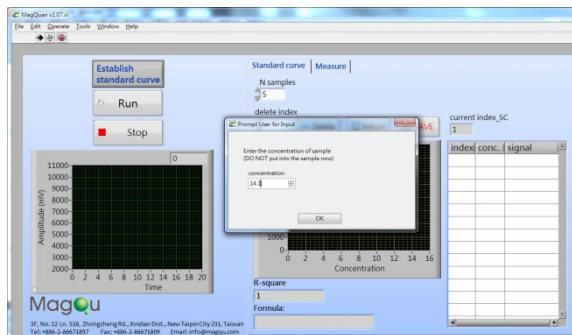
8. After clicking "OK" button of the dialog box as shown above, the program begins to read the signal. For each standard sample, the signal in case of that the analyzer is not loaded with a sample is detected. The detected signal is displayed in the lower left diagram. When the detection is finished, another dialog box will show up to ask you to put the standard sample into the analyzer, as shown below.
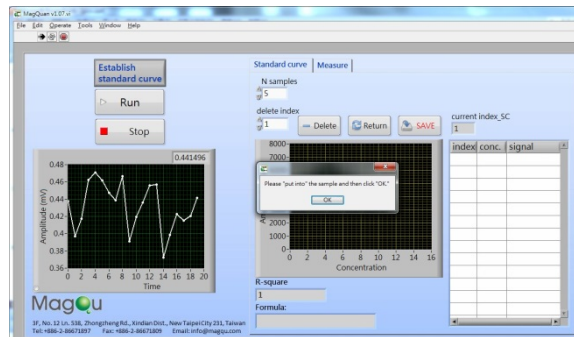
9. Load the sample into the analyzer and click "OK", the program starts to read signals for a standard sample. This signal strength should be higher than the signal of the analyzer without sample, as shown in the lower left diagram. When the detection is finished, another dialog box will show up to ask you to remove the sample from the analyzer.
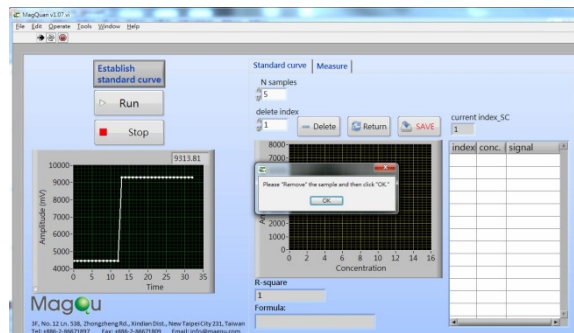
10. After removing the sample and clicking "OK", the index, magnetic concentration, and signal (the amplitude of the AC magnetic susceptibility) of the standard sample are displayed in the right table, as shown below.
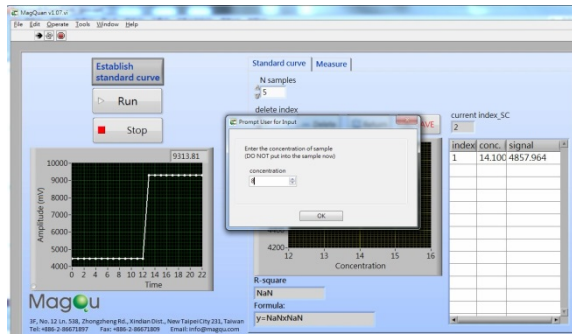
11. Repeat steps 7-10 sequentially to measure the amplitude of the ac magnetic susceptibility of other standard samples. When AC susceptibility measurements for all the standard samples are completed, the amplitude of the ac magnetic susceptibility as a function of the magnetic concentration is plotted in the middle diagram. The linear relationship between the amplitude of the ac magnetic susceptibility and magnetic concentration is obtained and its linear equation shown in the "Formula", as well as guided with the red line. Goodness of fit of the linear equation and measurement data is displayed in "R-square", as shown below. The relationships between amplitude ac susceptibility $\chi_{ac,0}$ and magnetic concentration has been established.
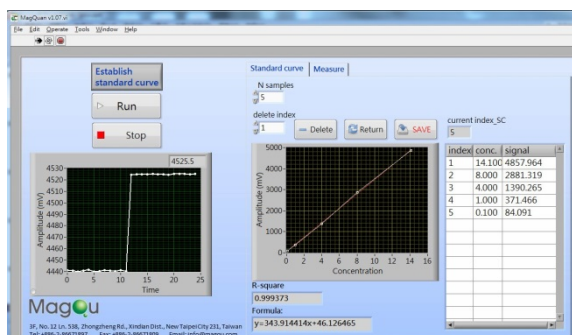
12. To remove some of the standard sample measurement results, enter the index number of the sample to be deleted in the "delete index", and then press the

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"Delete" button. The deleted measurement results will not be used to establish the relationship between $\chi_{ac,0}$ and magnetic concentration, but the deleted measurement results are still saved.

13. To recover the deleted data in step 12, please click the "Return" button. It will return to the initial results

14. When you press the "Save" button, the measured data are saved in the file name entered in step 6

15. Note: To measure the magnetic concentration of the sample, the amount of sample to be tested must be the same as standard samples.

The second stage: Use the established relationship between the amplitude of the AC magnetic susceptibility Xac,o and magnetic concentration to measure the concentration of the unknown samples.

1. Initiate the program MagLysis-Dev1.exe. The following window shows up.
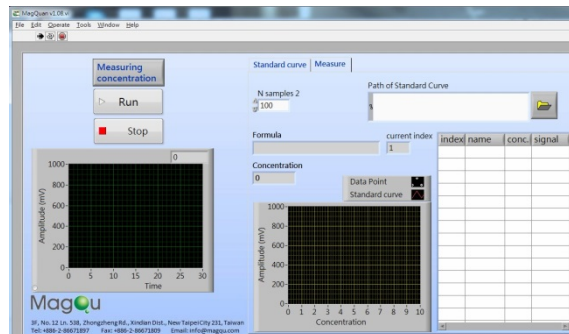
2. Confirm the button shows "Measuring concentration". If not, click the button to switch to "Measuring concentration ".

3. In "N samples 2", enter the numbers of samples to be tested. For example, we have prepared 2 unknown samples, enter "2".

4. Click "Run" button, the following pop up dialog box will indicate that you have not yet selected the standard relationship files between the amplitude AC susceptibility $\chi_{ac,0}$ and the magnetic concentration.
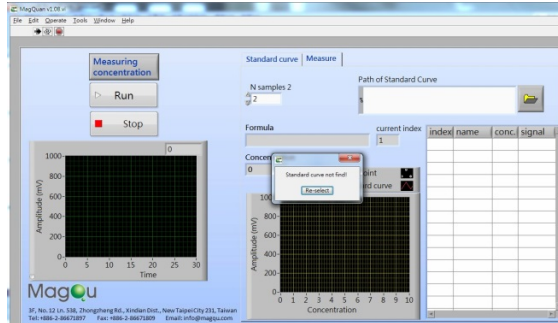
5. Click on "Re-select" button, the program will ask you to choose a standard relationship file, which has been established at the first stage.
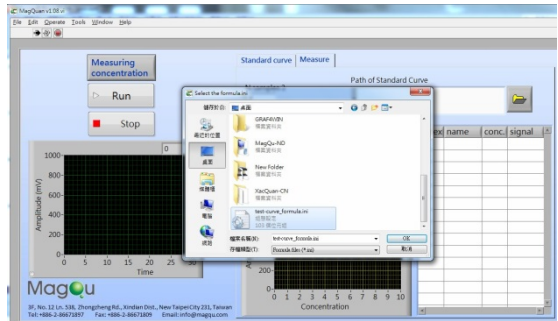
6. After selecting ini file and clicking "OK" button, file path and name of the selected ini file will be displayed in the "Path of Standard Curve" tab at the upper right of screen. And a dialog box shows up to ask you which path you would like to save the TXT file. As shown below.
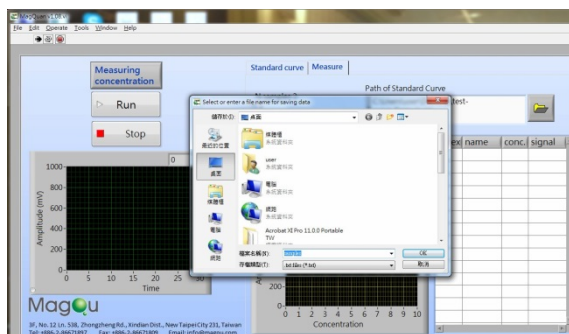
7. After entering the file name and clicking on OK, "Formula" column will show the linear relationship between the amplitude of the ac susceptibility $\chi_{ac,0}$ and magnetic concentration. And a dialog box shows up to ask you to enter the name of the first sample, such as input "sample 1"(It would be also a blank).
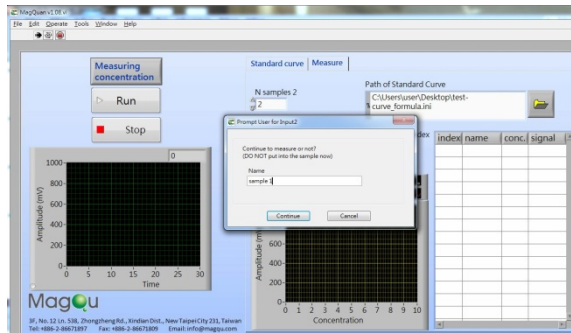
8. Enter the first name of the sample and press the "Continue", the program starts to read the signal when the analyzer is not loaded with a sample. The detected signal is displayed in the lower left diagram. When the detection is finished, another dialog box shows up to ask you to put the sample into the analyzer, as shown below.
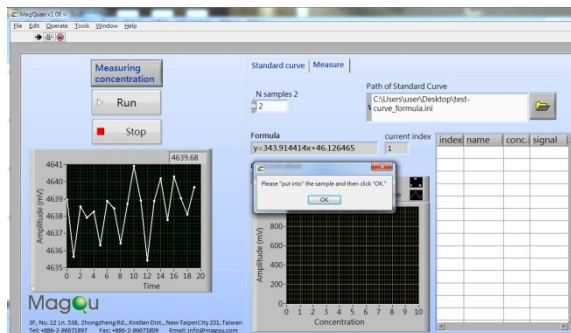
9. Load the first sample into the analyzer and click "OK", signals for the first sample are detected. When the detection is finished, another dialog box shows up to ask you to remove the sample from the analyzer.
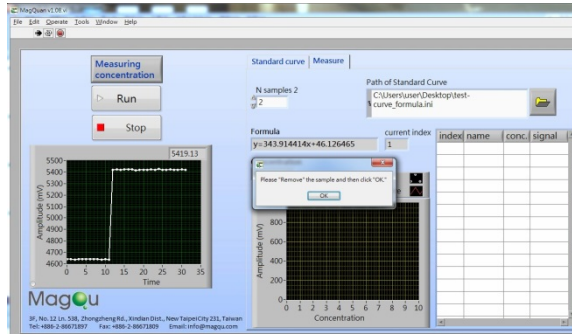
10. After removing the sample and clicking on "OK", the magnetic concentration of the first sample will be displayed in the right table, as shown below. In this case, we obtain the magnetic concentration is 2.142. Magnetic concentration unit is the same as the established standard relationship. The index of the first sample in the right table is "1"; the entered sample name in step 9 appears in the "name" tab. And then a dialog box shows up to ask you to enter the name of the second sample, such as input "sample 2". After clicking "OK", the program starts to read signals for the sample. If you want to abort the measurement, click "Cancel". Measured results will be stored in the TXT file entered file name in step 6.
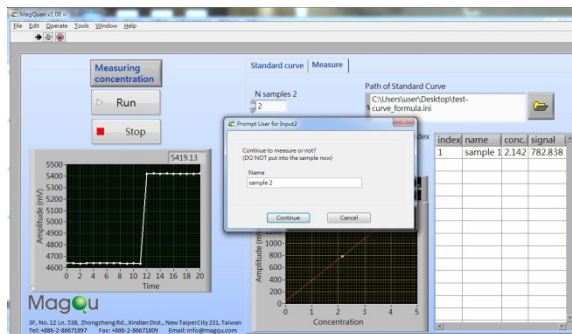
11. Repeat steps 8-10 sequentially measuring the concentration of other samples. When the measurements of all of the samples are completed, the results will show in right table. The measurement results will be stored in the TXT file entered file name in step 6.

Appendix A Installation Instructions of NI USB-6000

Appendix B Specification Chart

1. Input voltage： AC 100 – 240 V/50-60 Hz

2. Operation frequency: 20 kHz

3. The amplitude of AC magnetic field: < 50 Gauss

4. The volume of the liquid sample to be tested: ≤ 0.2 ml

5. The mass of the solid sample to be tested: ≤ 200 mg

6. Sensitivity: ~ 5 µg Fe or 0.001 emu

7. Connection to the computer via USB cable

8. Operation software platform: Windows XP/Windows 7

Appendix C List of Product and Accessories

Overview of products and accessories

Item	Quantity
MagQuan	1
Cable (with USB terminal on both ends)	1
Cable (power line)	1
Operation software (CD)	1
Operation and maintenance manual	1

Appendix D Warning Illustration

 This way up

 Fragile

 Keep dry

 Keep off magnetic field

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MagQu Co., Ltd.
3F, No. 12, Lane 538, Zhongzheng Rd., Xindian Dist., New Taipei City 231, Taiwan
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