Frequency Dependent Magnetic Susceptibility Analyzer

# XacQuan

# Operation and Maintenance Manual

Version-202501

# Contents



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## 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 on 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 or component.

**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.

# 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 Principle of AC Magnetic Susceptibility Measurement

Under an external magnetic field, the direction of magnetic dipoles of a magnetic substance tends to be along the direction of the external magnetic field. If the external magnetic field is an alternative-current (AC) magnetic field with low AC frequency (generally lower than microwave frequency), the magnetic dipole oscillates with this AC magnetic field. This is the physical origin of AC magnetic susceptibility of a magnetic substance. 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 and the external AC magnetic field. Therefore, the AC magnetic susceptibility $\chi_{ac}$ of a material can be expressed as $\chi_o e^{i\theta}$, where $\chi_o$ represents the amplitude of the magnetic susceptibility of the material, and $\theta$ is the phase difference of magnetic dipole with respect to the external magnetic field.

In addition to using magnetic susceptibility strength $\chi_o$ and phase difference $\theta$ to express AC magnetic susceptibility $\chi_{ac}$ of a material, one can expand $\chi_o e^{i\theta}$ into the form as $\chi_o cos\theta + i\chi_o sin\theta$. $\chi_{ac}$ can then be expressed as $\chi_r + i\chi_i$, where $\chi_r = \chi_o cos\theta$ known as the real part of AC magnetic susceptibility, and $\chi_i = \chi_o sin\theta$ known as the imaginary part of AC magnetic susceptibility. Therefore, the AC magnetic susceptibility $\chi_{ac}$ of a material can be expressed in terms of $\chi_r$ and $\chi_i$.

The AC magnetic susceptibility of a magnetic substance varies with the frequency of external magnetic fields. Frequency Dependent Magnetic Susceptibility Analyzer: XacQuan introduced by MagOu Co., Ltd has a major function being capable of measuring the real part $\chi_r$ and the imaginary part $\chi_i$ (or the amplitude $\chi_o$ and phase difference $\theta$) of magnetic susceptibility of a magnetic substance under magnetic fields of various frequencies. The frequency adjustable range is 10 Hz to 25 kHz.

The measurement principle of XacQuan is outlined as followed. The analyzer initially measure the amplitude of the magnetic susceptibility $\chi_{o,air}$, and the phase difference $\theta_{air}$ detected without the presence of sample (i.e. the air) and of the external magnetic field. Thus, the magnetic susceptibility upon air sample can be expressed as $\chi_{air} = \chi_{o,air}e^{i\theta air}$. Next, after placing the sample in XacQuan, the amplitude of the magnetic susceptibility $\chi_{o,mix}$ and the phase difference $\theta_{mix}$ are detected, which results in the magnetic susceptibility $\chi_{mix} = \chi_{o,mix}e^{i\theta mix}$. The magnetic susceptibility $\chi_{mix}$ detected with the presence of sample is actually the contribution from both the air and the sample. Therefore, one can deduct $\chi_{air}$ from $\chi_{mix}$ to get the magnetic susceptibility of the sample $\chi_{sample} = \chi_{mix} - \chi_{air} = \chi_{o,mix}e^{i\theta mix} - \chi_{o,air}e^{i\theta air} = \chi_{o,sample}e^{i\theta sample}$. In this analysis, the ratio of $\chi_{sample}$ to $\chi_{air}$, $\chi_{o,sample}/\chi_{o,air}$, and the phase difference $\theta$ of relative magnetic susceptibility of a magnetic substance can be calculated through measuring $\chi_{o,air}$, $\chi_{o,mix}$, $\theta_{air}$, and $\theta_{mix}$.

Furthermore, the real part (= $\chi_{o,sample}/\chi_{air}$ x $cos\theta_{sample}$ ) and the imaginary part (= $\chi_{o,sample}/\chi_{air}$ x $sin\theta_{sample}$ ) of magnetic susceptibility of the to-be-detected substance are avaliable.

According to the above principle, the flow chart of using XacQuan to measure the magnetic susceptibility of the to-be-detected substance under a certain AC external magnetic field is shown in Figure 1.

For XacQuan, an AC voltage is provided with an external function generator to generate AC current flowing through the solenoid, thereby creating an AC magnetic field inside the coil. When placing the to-be-detected magnetic substance in this solenoid, it would be subjected to AC magnetic field action and triggered to generate AC magnetic susceptibility signal.

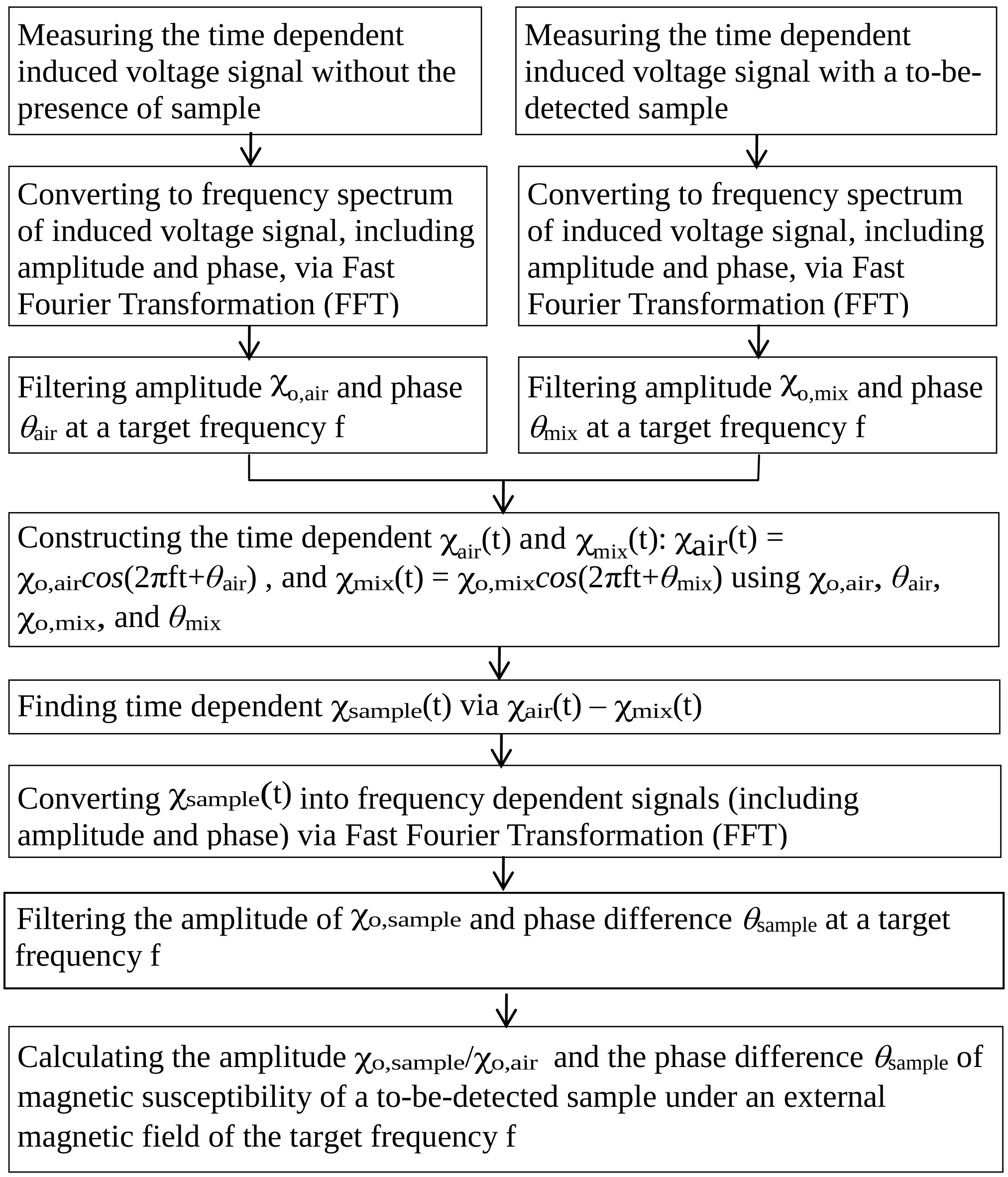

Figure 1. Flow chart of measuring frequency dependent magnetic susceptibility.

For XacQuan, Faraday coil is used to convert this AC magnetic susceptibility signal into induced AC voltage signal, and it is input into computer software after passing through the amplifier circuit and signal capturing unit. Fast Fourier Transformation (FFT) is then used to analyze the magnetic susceptibility size of the real part $\chi_r$ and the imaginary part $\chi_i$ of the magnetic substance at a target frequency of AC magnetic field. Through changing the AC voltage output's frequency from function generator, we are able to establish the frequency dependent AC magnetic susceptibility of the magnetic substance.

In Chapter 2, we introduce all the major components that constituted XacQuan.

# Chapter 2 Introduction of XacQuan

The structural diagram of XacQuan is shown in Figure 2. XacQuan is composed of the following main components:

1. Function generator
2. Coil assembly
3. Partial voltage compensation circuit
4. Signal amplifier circuit
5. Data acquisition unit
6. Fast Fourier Transformation (FFT) software

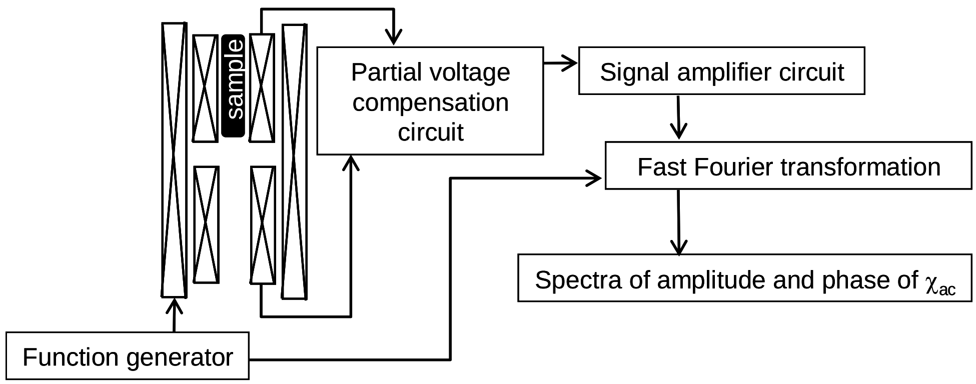


Figure 2. Structural diagram of XacQuan

The specifications and functions of all components shown in Figure 2 are described in the following sections.


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## Section 1 Function Generator

The function generator used in XacQuan is NI USB-6211, as shown in Figure 3.


Figure 3. Function generator NI USB-6211 used in XacQuan.

## Section 2 Coil Assembly

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

1. Excitation coil

   The sectional diagram of excitation coil is shown in Figure 4. It is made of ABS material being wound with copper wire around its exterior. After being detected by a LCR meter, the impedance of this excitation coil in response to frequency f changes is shown in Figure 5.

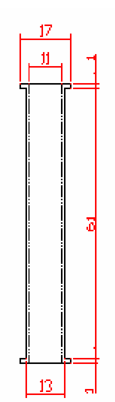



Figure 4. Sectional diagram of excitation coil

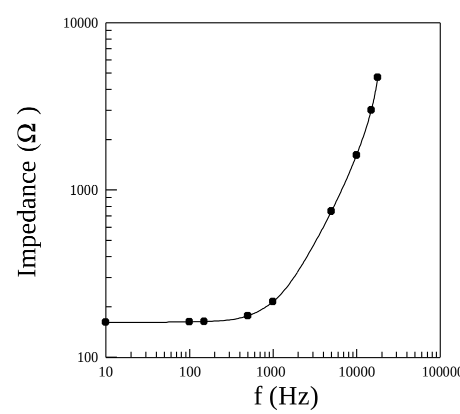



Figure 5. Impedance of excitation coil in response to frequency f.

2. Faraday coil

The Faraday coil adopted here belongs to a type of gradient Faraday coil, its sectional diagram of which is shown in Figure 6.

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 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.

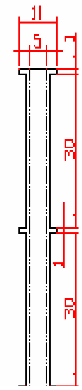



Figure 6. Sectional diagram of gradient Faraday coil.

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 7.

The principle of Faraday coil is that a voltage is 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.

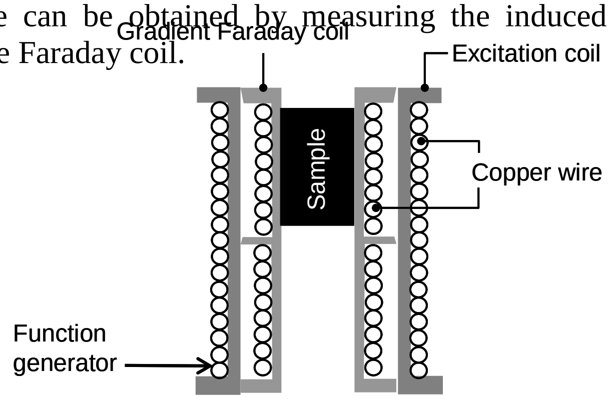



Figure 7. Relative positions of excitation coil, gradient Faraday coil, and sample in the coil assembly of XacQuan.

## Section 3 Partial Voltage Compensation Circuit

To further eliminating induced voltage across gradient Faraday coil due to the AC magnetic field generated by excitation coil, XacQuan is equipped with the partial voltage compensation circuit. Its circuitry is shown on the left side of the dashed box in Figure 8. The top and bottom sections of the gradient Faraday coil are connected with a 5-kΩ resistor and a variable 100-Ω resistor in series, respectively, and each is being subtracted by the voltages across 5-kΩ resistors. Finally, the voltage from both terminals of AB is led to signal amplifier circuit.

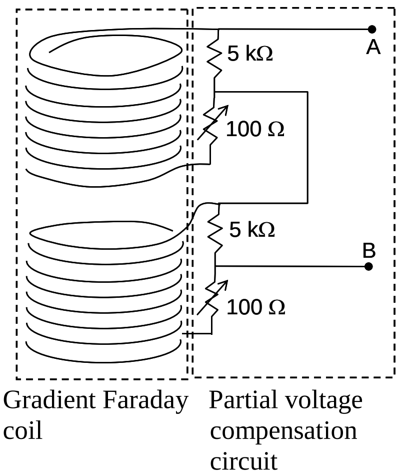



Figure 8. Output signal of voltage sensed with gradient Faraday coil after passing through the partial voltage compensation circuit.

## Section 4 Signal Amplifier Circuit

The circuitry of this signal amplifier circuit, as shown in Figure 9(a) and 9(b), is mainly an instrument amplifier. The output voltage from the partial voltage compensation circuit is input to this amplifier circuit to increase the S/N ratio. The relationship between the gain of the signal amplifier circuit (Amp.) and the frequency f of input voltage ($V_{in}$) is shown in Figure 10.

(a) (b)

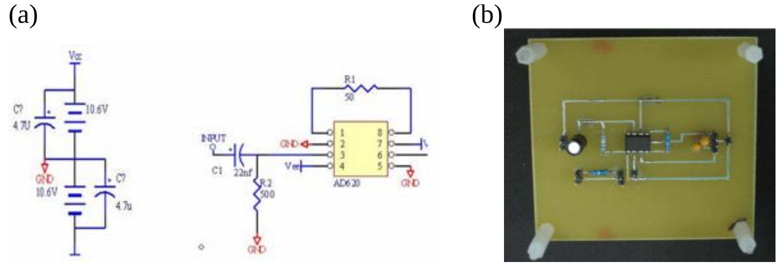


Figure 9. Schematic diagram (a) and actual photo (b) of signal amplifier circuit.

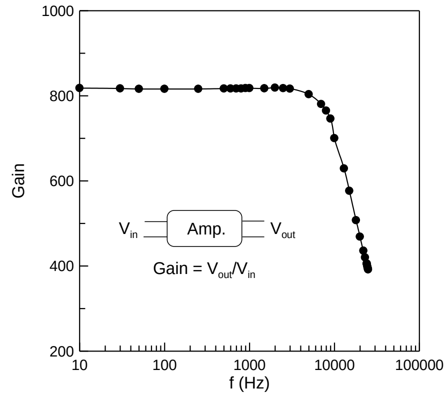



Figure 10. Relationship between the gain of the signal amplifier circuit (Amp.) and the frequency f of input voltage ($V_{in}$).

## Section 5 Data Acquisition Unit

The data acquisition unit NI USB-6211 adopted with XacQuan is shown in Figure 11. NI USB-6211 transmits this signal to the computer for data processing through USB terminal. Please refer to the attached operation manual for detailed specifications.


Figure 11. Data acquisition card NI USB-6211.

## Section 6 Fast Fourier Transformation (FFT) And Analysis Software

The voltage signal output from data acquisition unit is time dependent and is then converted into frequency dependent via built-in FFT of operation program of XacQuan. The signals at a target frequency can be recorded as functions of time by using the operation program. Please refer to Chapter 3 for detailed descriptions.

# Chapter 3 Operation Procedures

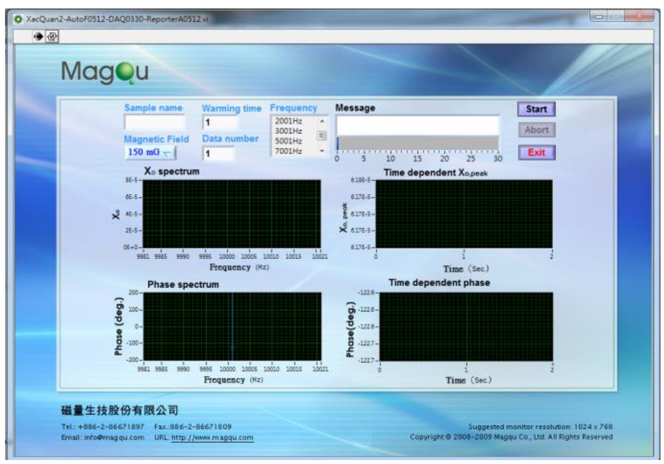
In this chapter, we would introduce the operation procedures of XacQuan.

## Section 1 Operation Program Installation And Equipment Startup

1. Install NI USB-6211 driver program according to the instructions stated in the operation manual.
2. Copy XacQuan2-AutoF0512.exe, XacQuan2-AutoSC0510.exe, and XacQuan2-AutoC0518.exe three files to a computer. These files are stored in Xac-f1 Software CD-ROM.
6. Connect the USB output terminal of XacQuan with the computer.
7. Connect XacQuan with power supply and switch it on. You have then completed the installation and startup procedures.

## Section 2 Measurement of Frequency Dependent $\chi_{ac}$

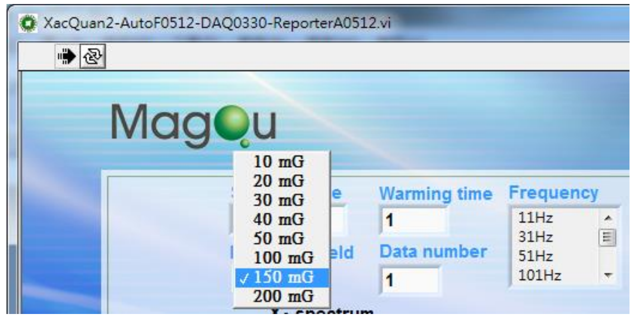
1. Initiate the program XacQuan2-AutoF0512.exe. The following window shows up.




2. Key in the sample name at “Sample name”. For example, key in test-sample at “Sample name”.


3. Click on “Magnetic Field” to select the amplitude of applied AC magnetic field. The selectable amplitude of applied AC magnetic field is either of 10 mG, 20 mG, 30 mG, 40 mG, and

50 mG, 100 mG, 150 mG or 200 mG. For example, 150 mG is selected.

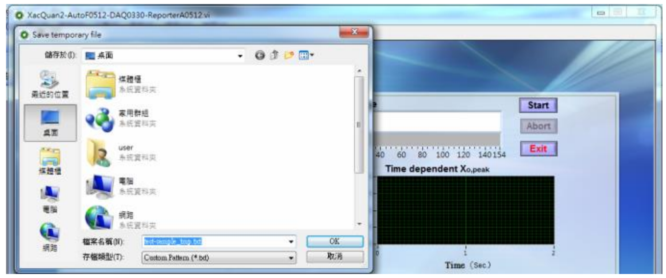



4. Set values for “Warming time” and “Data number”. The suggested value for “Warming time” is 2 or 3, while the value for “Data number” is 3-10. For example, “Warming time” is set as 2. “Data number” is set as 5.

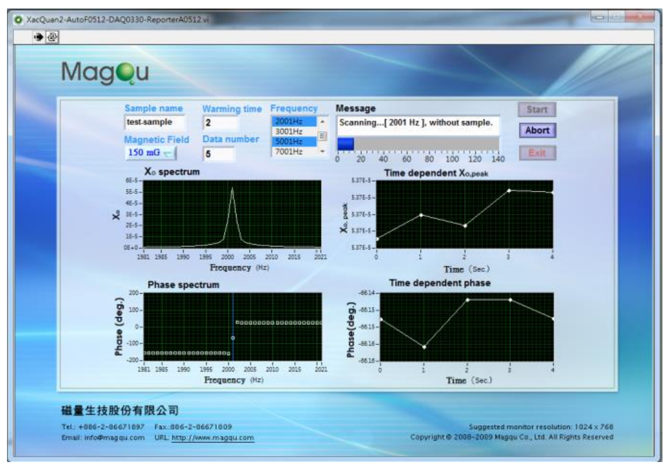

5. Select the frequencies of applied magnetic field at “Frequency”. The frequency range is from 21 Hz to 23801 Hz.


6. In newer version, keying in mass or volume is also available.

7. Click “Start”, the following window shows up to ask you to “Save temporary file” in a suitable directory. For example, the temporary file is saved on desktop. Then, click “OK”.




8. XacQaun starts to record the amplitudes and the phases for the case without sample.
9. The diagram block on the upper-left region is the spectrum of the amplitude of magnetic susceptibility of a substance, i.e. $\chi_o$-f curve. The frequency range of this spectrum is automatically adjusted according to the selected value in “Frequency”.




10. The time-evolution peak value in the $\chi_o$-f curve is plotted in the diagram block on the upper-right region, i.e. $\chi_{o,peak}$-t curve. The total numbers of the data points in the $\chi_{o,peak}$-t curve equal the summation of the values in “Warming time” and “Data number”. For example, the summation of the values in “Warming time” and “Data number” is 7, there will be 7 data points recorded and shown in $\chi_{o,peak}$-t curve. However, only the last 5 data points (value in “Data number”) are used for calculations of $\chi_{ac}$.

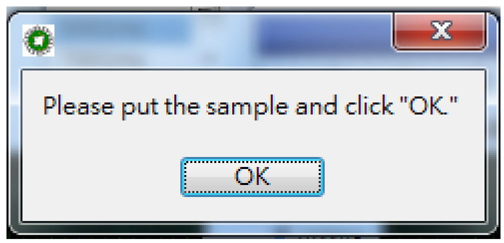
11. The diagram block on the lower-left region is the spectrum of the phase of magnetic susceptibility of a substance, i.e. phase-f curve. The frequency range of this spectrum is automatically adjusted according to the selected value in “Frequency”.

12. The time-evolution peak value in the phase-f curve is plotted in the diagram block on the lower-right region, i.e. phase-t curve. The total numbers of the data points in the phase-t curve equal the summation of the values in “Warming time” and “Data

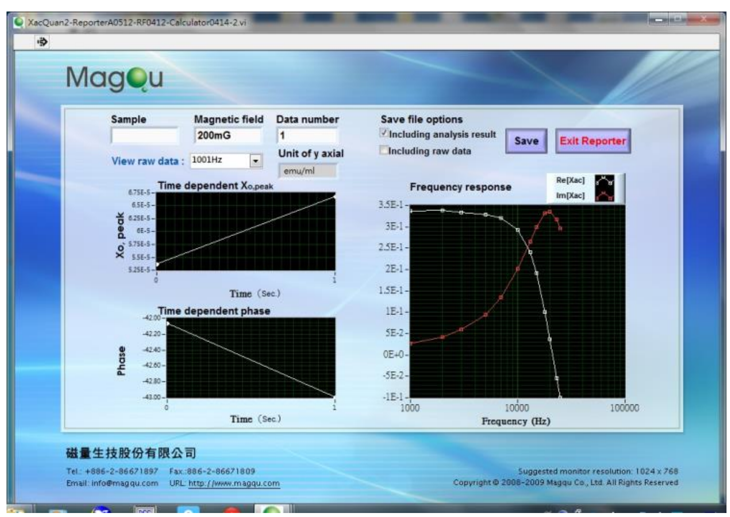
number”. For example, the summation of the values in “Warming time” and “Data number” is 7, there will be 7 data points recorded and shown in phase-t curve. However, only the last 5 data points (value in “Data number”) are used for calculations of $\chi_{ac}$.

13. The instant state of the measurement is shown in “Message”.

14. After finishing recording the signals for the case without sample, the following window shows up to ask you to put the sample into XacQuan.




14. Put the sample into XacQuan and click “OK”. XacQaun then records the amplitudes and the phases at frequencies for the case of with sample. Whenever finishing recording the amplitudes and the phases at frequencies, the following window shows up.

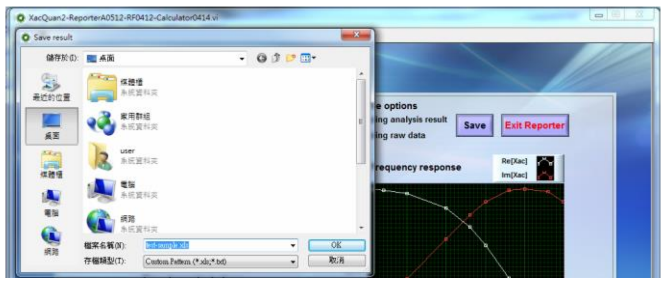


15. The real part (Re[$\chi_{ac}$], white line) and the imaginary part (Im[$\chi_{ac}$], red line) as functions of frequency for the tested sample are plotted in the right region.

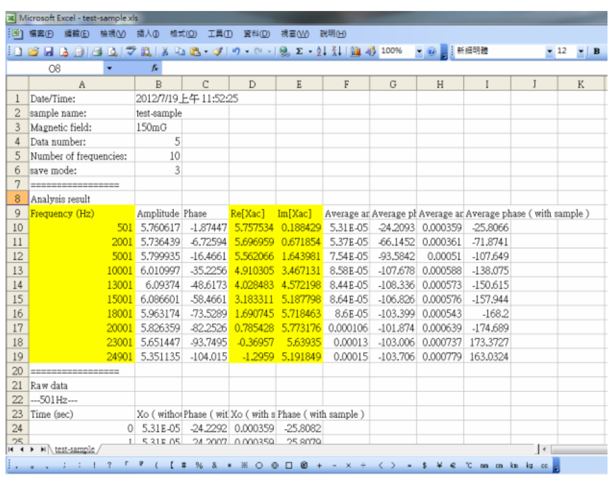
16. The data of $\chi_{o,peak}$ and phase at a given frequency for cases of without and with sample are plotted in the left region. The first 5 data (5 comes from the value in "Data number") are for the case of without sample, the other 5 data are for the case of with sample.

17. You can select the interested frequency in "View raw data" to view the data of $\chi_{o,peak}$ and phase at the interested frequency for cases of without and with sample are plotted in the left region.

18. Click "Including raw data" and then click "Save", the following window shows up to ask you to select a suitable directory to save the results. For example, the results are save as test-sample.xls on desktop.




19. You can open the test-sample.xls. The frequency is listed in column A, and Re[$\chi_{ac}$] and Im[$\chi_{ac}$] are listed in columns D and E, respectively.



| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Date/Time: | 2012/7/19 上午 11:52:25 | | | | | | | |
| 2 | sample name: | test-sample | | | | | | | |
| 3 | Magnetic field: | 150mG | | | | | | | |
| 4 | Data number: | 5 | | | | | | | |
| 5 | Number of frequencies: | 10 | | | | | | | |
| 6 | save mode: | 3 | | | | | | | |
| 7 | ================= | | | | | | | | |
| 8 | Analysis result | | | | | | | | |
| 9 | Frequency (Hz) | Amplitude | Phase | Re[Xac] | Im[Xac] | Average ar | Average pl | Average ar | Average phase ( with sample ) |
| 10 | 501 | 5.760617 | -1.87447 | 5.757534 | 0.188429 | 5.31E-05 | -24.2093 | 0.000359 | -25.8066 |
| 11 | 2001 | 5.736439 | -6.72594 | 5.696959 | 0.671854 | 5.37E-05 | -66.1452 | 0.000361 | -71.8741 |
| 12 | 5001 | 5.799935 | -16.4661 | 5.562066 | 1.643981 | 7.54E-05 | -93.5842 | 0.00051 | -107.649 |
| 13 | 10001 | 6.010997 | -35.2256 | 4.910305 | 3.467131 | 8.58E-05 | -107.678 | 0.000588 | -138.075 |
| 14 | 13001 | 6.09374 | -48.6173 | 4.028483 | 4.572198 | 8.44E-05 | -108.336 | 0.000573 | -150.615 |
| 15 | 15001 | 6.086601 | -58.4661 | 3.183311 | 5.187798 | 8.64E-05 | -106.826 | 0.000576 | -157.944 |
| 16 | 18001 | 5.963174 | -73.5289 | 1.690745 | 5.718463 | 8.6E-05 | -103.399 | 0.000543 | -168.2 |
| 17 | 20001 | 5.826359 | -82.2526 | 0.785428 | 5.773176 | 0.000106 | -101.874 | 0.000639 | -174.689 |
| 18 | 23001 | 5.651447 | -93.7495 | -0.36957 | 5.63935 | 0.00013 | -103.006 | 0.000737 | 173.3727 |
| 19 | 24901 | 5.351135 | -104.015 | -1.2959 | 5.191849 | 0.00015 | -103.706 | 0.000779 | 163.0324 |
| 20 | ================= | | | | | | | | |
| 21 | Raw data | | | | | | | | |
| 22 | ---501Hz--- | | | | | | | | |
| 23 | Time (sec) | Xo ( withor | Phase ( wit | Xo ( with s | Phase ( with sample ) | | | | |
| 24 | 0 | 5.31E-05 | -24.2292 | 0.000359 | -25.8082 | | | | |
| 25 | 1 | 5.31E-05 | -24.2007 | 0.000359 | -25.8079 | | | | |



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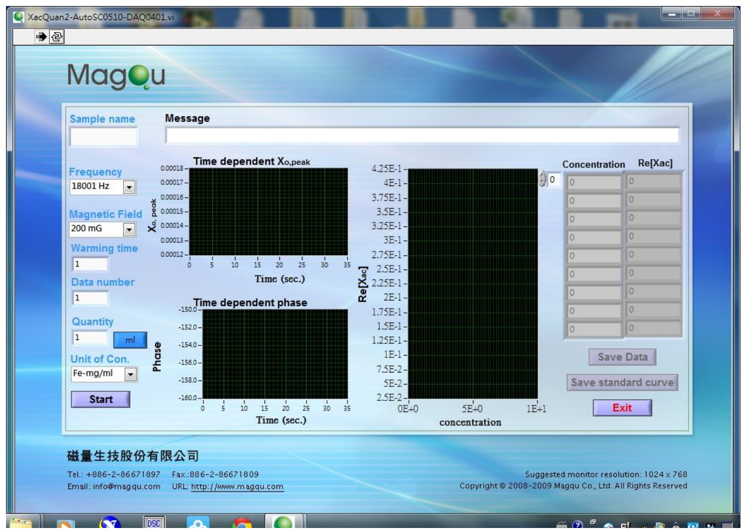
20. Click “Exit Reportor”, and then click “”Exit” to shut down the program. The measurement of frequency dependent $\chi_{ac}$ has been finished.

## Section 3 Measurement of Magnetic Concentration

### Section 3A Establishment of Re[$\chi_{ac}$] vs. magnetic concentration

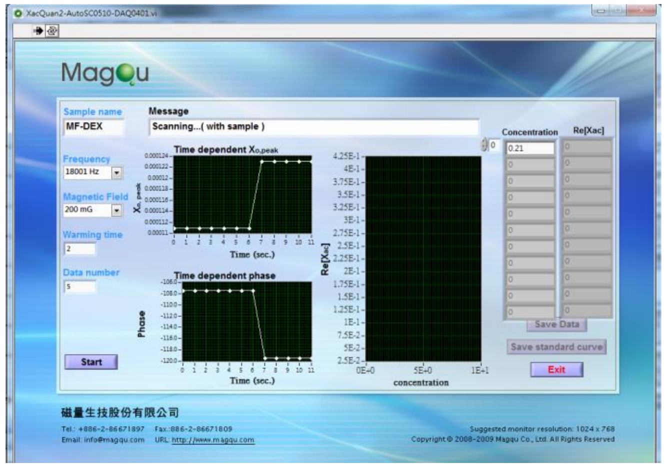
1. Initialize the program XacQuan2-AutoSC0510.exe, the following window shows up.



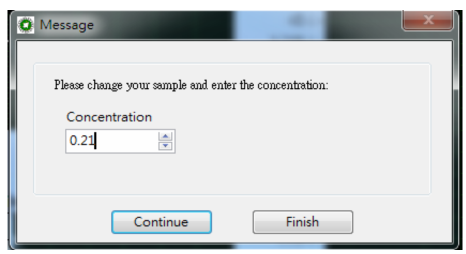

2. Key in the sample name in “Sample name”, select the interested frequency” Frequency”, select the amplitude of the ac magnetic field in “Magnetic Field”, key in values in “Warming time” and “Data number”. For example, “Sample name” can be MF-DEX, the “Frequency” is 18001 Hz. The amplitude of ac magnetic field is 200 mG. The values in “Warming time” and “Data number” are 1 and 1, respectively. In newer version, keying in mass or volume of sample is also available.

3. Click “Start” to record the signals for the case of without sample.

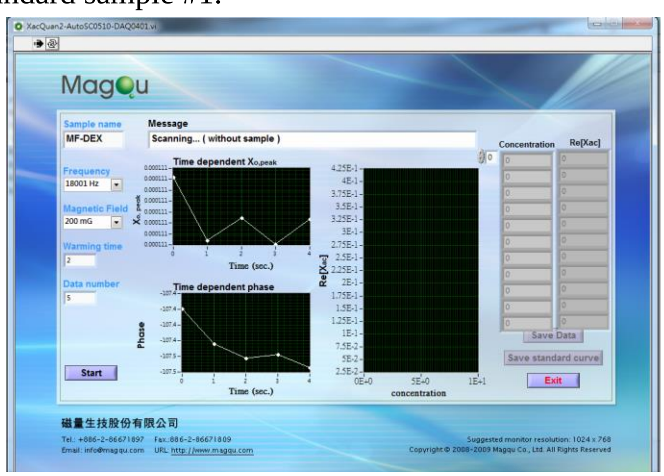
4. The time-evolution $\chi_{o,peak}$ is shown in “Time dependent $\chi_{o,peak}$” in the upper-left region. The time-evolution phase of $\chi_{ac}$ is shown in “Time dependent phase” in the lower-left region.




5. Whenever the recording of the $\chi_{o,peaj}$ and phase for the case of without sample, a message window shows up to ask you load the standard sample #1 to XacQuan and input the magnetic concentration of the standard sample #1. For example, the magnetic concentration of the standard sample #1 is 0.21 emu/g.




6. Once you have loaded the standard sample #1 to XacQuan and input the magnetic concentration in the message window, click “Continue”. XacQuan then records the signals for the case of standard sample #1.



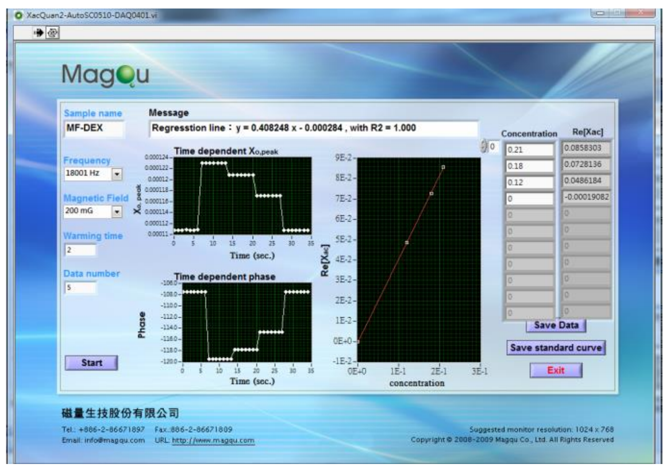
7. Whenever the recording of the $\chi_{o,peaj}$ and phase for the case of standard sample #1, a message window shows up to ask you load the standard sample #2 to XacQuan and input the magnetic concentration of the standard sample #2. For example, the magnetic concentration of the standard sample #2 is 0.18 emu/g.

8. Once you have loaded the standard sample #2 to XaQuan and input the magnetic concentration in the message window, click "Continue". XacQuan then records the signals for the case of standard sample #2.

9. Repeat steps 7 and 8 for the following standard samples.

10. The final standard sample is the case of without sample. Thus, input 0 in the message window and click "Continue" to record the signals without sample.

11. The Re[$\chi_{ac}$] for each standard sample is calculated, as shown in the blocks in the right region. The Re[$\chi_{ac}$] as a function of the magnetic concentration is plotted in the diagram in the right region. The linear relationship between Re[$\chi_{ac}$] and the magnetic concentration is obtained and shown in the "Message", as well as guided with the red line.

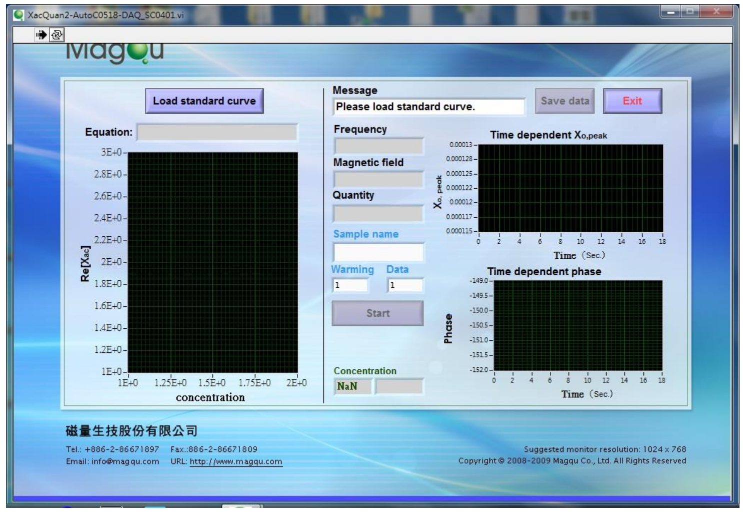



12. Click "Save standard curve" to save the linear relationship between Re[$\chi_{ac}$] and the magnetic concentration, as well as the results in a suitable directory. For example, all the results are saved as MF-DEX.txt on desktop

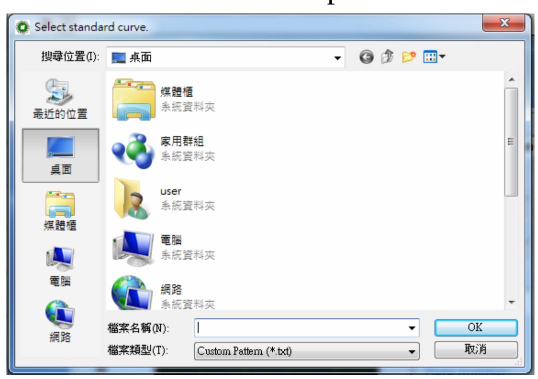
13. Click “Exit” to shutdown the program.

**Section 3B Determination of magnetic concentration**

1. Initialize the program XacQuan2-AutoC0518.exe, the following window shows up.

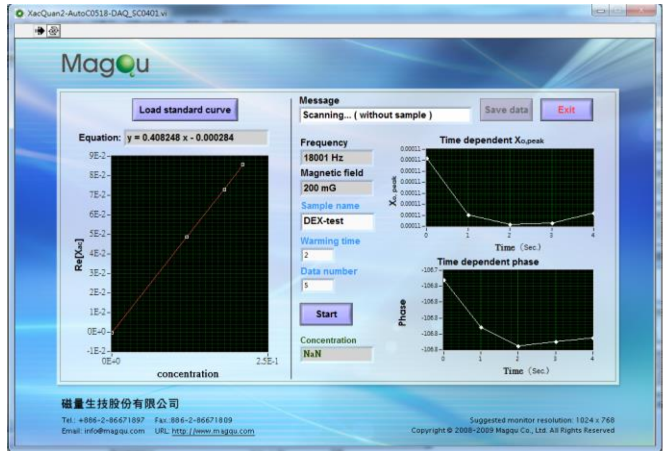



2. Click “Load standard curve” to select the file for the relationship between Re[$\chi_{ac}$] and the magnetic concentration. For example, select the file MF-DEX.txt on desktop.

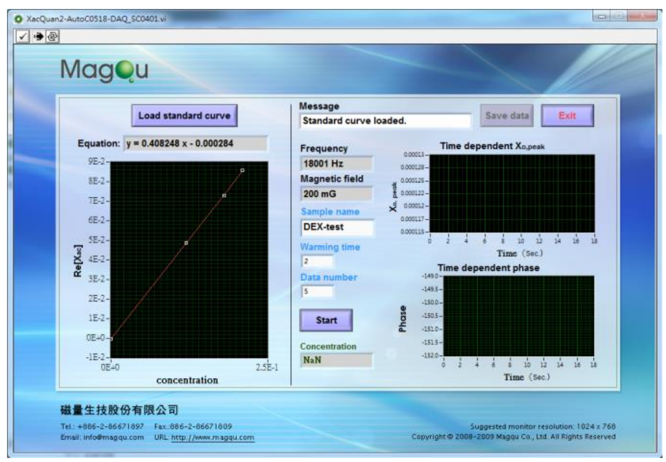



3. Once the file for the standard curve is selected, the standard curve is shown in diagram in the left region. The analytic function for the standard curve is shown in “Equation:” In newer version the quantity of sample mass or volume is also available.

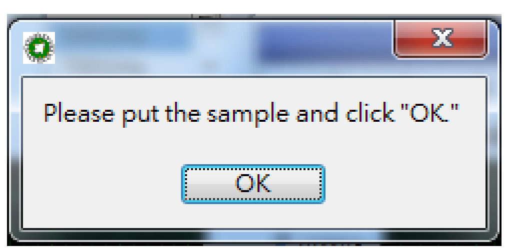
4. Key in the name of the tested sample in “Sample name”. Input the values for “Warming time” and “Data number”. It is worthy that the values for “Warming time” and “Data number” should be the same as those in step 2 in Section 3A.



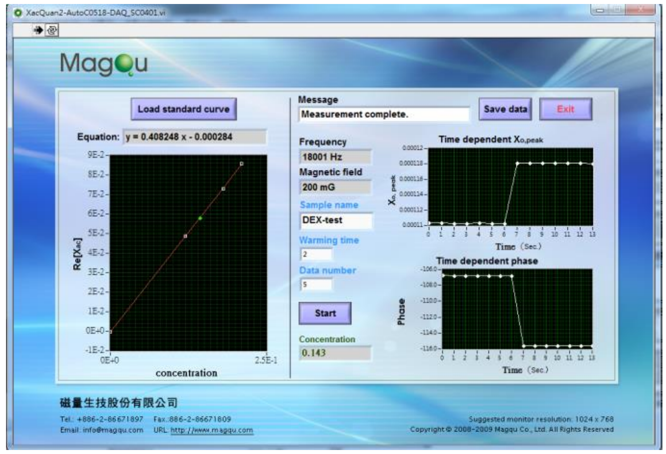

5. Click “Start” to record the signals for the case of without sample. The time-evolution $\chi_{o,peak}$ is shown in “Time dependent $\chi_{o,peak}$” in the upper-right region. The time-evolution phase of $\chi_{ac}$ is shown in “Time dependent phase” in the lower-right region.



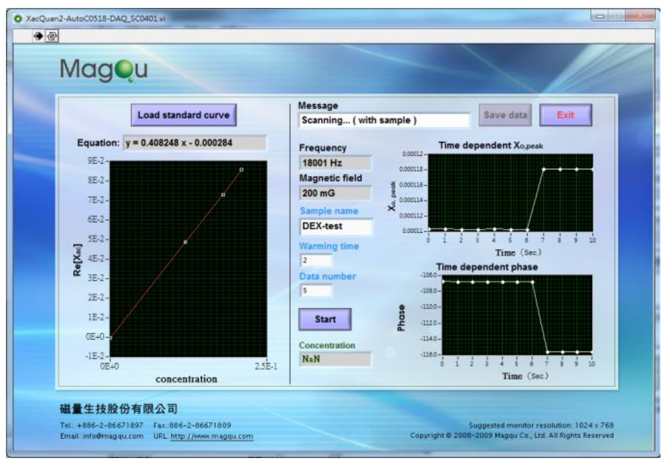

6. Whenever the recording of the $\chi_{o,peaj}$ and phase for the case of without sample, a message window shows up to ask you load the tested sample to XacQuan and then click “OK”.




7. Once you have loaded the tested sample to XaQuan and click “OK”, XacQuan then records the signals for the case of the tested sample.




8. Whenever the signals of the tested sample have been detected, the Re[$\chi_{ac}$] of the tested sample is analyzed, and is labeled in the standard curve with a green point. The corresponding magnetic concentration is shown in "Concentration". For example, the magnetic concentration of the tested sample is found as 0.143, in unit of the same as that of standard samples.



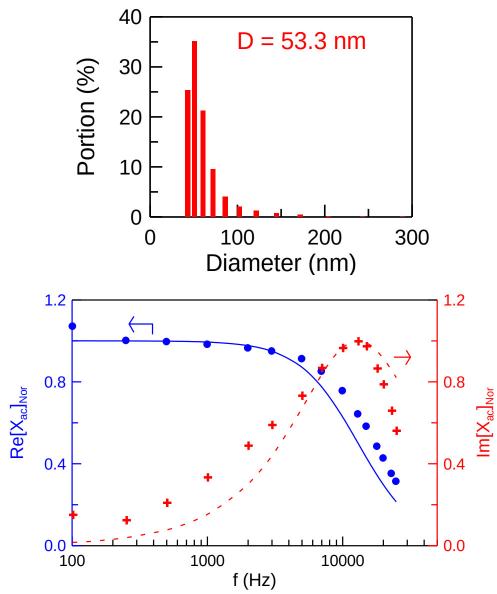

9. Click "Save data" to save the results in as suitable directory.

10. Click "Exit" to shutdown the program.

# Chapter 4 Application Examples

**Example 1:**

The example given here is to measure the frequency dependent ac magnetic susceptibility of magnetic fluid. The concentration of magnetic fluid is 0.3 emu/g. The mean diameter of magnetic nanoparticles is around 50 nm. The real part Re[$\chi_{ac}$] and the imaginary part Im[$\chi_{ac}$] of the magnetic fluid are measured as the frequency of the ac applied magnetic field by using XacQuan, as shown below.




According to the Im[$\chi_{ac}$]-f curve, there exists a frequency at which the absorption of ac magnetic energy by magnetic nanoparticles is maximum. This evidences the resonance of oscillating magnetic nanoparticles dispersed in water under ac magnetic field.

In fact, the Re[$\chi_{ac}$]-f and the Im[$\chi_{ac}$]-f curves can be used as spectra to identify the magnetic composition. Once the composition of magnetic material is changed, the behaviors of $\chi_{ac}$ spectra vary. Thus, XacQuan can be applied in determinations of magnetic composition for materials.

**Example 2:**

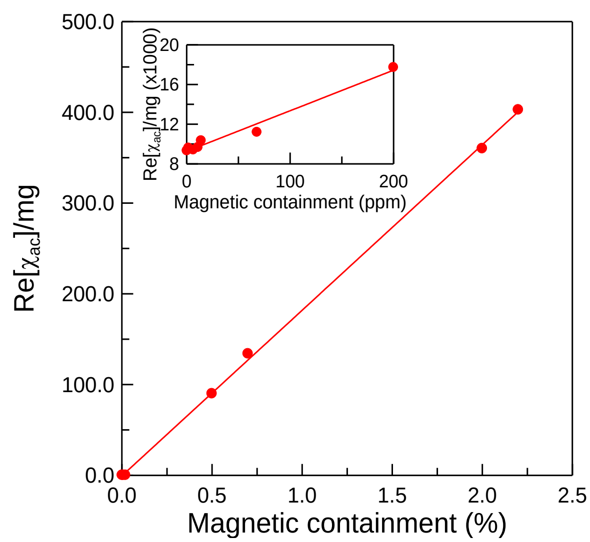
One of important trends in green industry is "green cars" using batteries. The most popular batteries are Li-battery. The cathode material for Li-battery is $LiFePO_4$. Lots of companies are manufacturing $LiFePO_4$.

The source materials for producing $LiFePO_4$ include iron oxide, which is one kind of magnetic material. Once the concentration of magnetic containment is too high, say 1 %, the charge-discharge properties of Li-battery are seriously degraded. Thus, it is necessary to check the magnetic containment in $LiFePO_4$.

The currently used method to detect the magnetic containment is Inductively-Coupled Plasma (ICP). However, it usually takes time and cots a lot to operate ICP. Hence, there is a need to have a convenient, low-cost, high-throughput, accurate, and compact analyzer to quantitatively detect the magnetic containment in $LiFePO_4$. XacQuan is definitely the analyzer for this issue.

Several $LiFePO_4$ powers with various concentrations for magnetic containment are prepared. The real parts Re[$\chi_{ac}$] of ac magnetic susceptibility at a given frequency are detected by using XacQuan. The relationship between Re[$\chi_{ac}$] and the concentration of the magnetic containment is obtained, as shown below. It is clear that the Re[$\chi_{ac}$] increases linearly with the increasing concentration of magnetic containment. It is easy to determine the concentration of magnetic containment is higher or lower than 1 %. Hence, XacQuan is powerful for the application of quantitatively detecting the concentration of magnetic containment in $LiFePO_4$.

As to the detection limitation, the Re[$\chi_{ac}$] for low-concentrated magnetic-containment $LiFePO_4$ is detected by using XacQuan. The results are shown in the insert. It was found that the low-detection limit for the concentration of magnetic containment is around 10 ppm (= 0.001 %).

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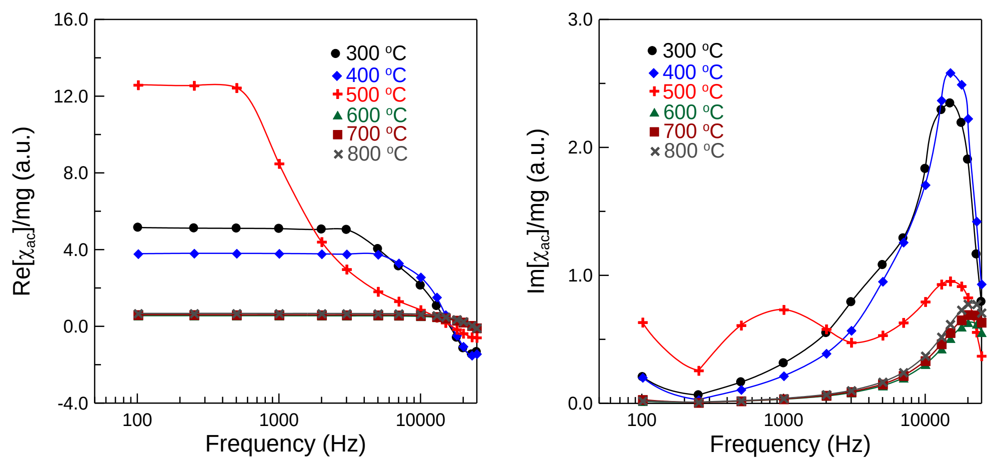
**Example 3:**

Recently, amorphous metal FeSi alloy attracts lots of interests from R&D people because of its high magnetization and low heat dissipation. FeSi amorphous metal is very useful as cores of transformers or motors. Many research groups and companies are working on preparing high-quality FeSi amorphous metal. However, there are many steps for producing high-quality amorphous metal. It is necessary to check the magnetic qualities after each step. XacQuan is good for the quick check.

For example, during the manufacture, FeSi amorphous metal is annealed at high temperatures. There exits a suitable temperature range for achieving high quality. By using XacQuan to measuring the real part Re[$\chi_{ac}$] and the imaginary part Im[$\chi_{ac}$] of FeSi amorphous metals annealed at different temperatures, the annealing processes can be determined.

The real parts Re[$\chi_{ac}$] and the imaginary parts Im[$\chi_{ac}$] of several FeSi amorphous metal samples annealed at different temperatures from 300 $^{o}$C to 800 $^{o}$C are measured by using XacQuan. The results are shown below. Since Re[$\chi_{ac}$] denotes the magnetization, and Im[$\chi_{ac}$] denotes the heat dissipation, we would like to find the annealing temperature at which FeSi amorphous metal can show the high Re[$\chi_{ac}$] and low Im[$\chi_{ac}$]. According to the results, the best temperature to anneal FeSi amorphous metal is around 500 $^{o}$C.

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## Appendix A Specification Chart

- Width: 400 mm, height: 321 mm, depth: 135 mm
- Weight: 5.0 kg
- Input voltage: 100 - 250 VAC/ 50 - 60 Hz
- Solenoid assembly specifications:
  Excitation coil: resistance = 100 ~ 200 Ω
  Coil density = 400 ~ 550 turns/cm
  Read coil: resistance = 40 ~ 70 Ω
  Coil density = 400 ~ 550 turns/cm
- Operation frequency: 21 - 23801 Hz, best in 1001 – 22001Hz
- Operation software platform: Windows XP/Windows 7

# Appendix B List of Product And Accessories

| Overview of XacQuan and accessories | |
|---|---|
| Item | Quantity |
| XacQuan | 1 |
| Cable (with USB terminal on both ends) | 1 |
| Cable (power line) | 1 |
| Operation software (CD) | 1 |
| Operation and maintenance manual | 1 |

# Appendix C  Warning Icon Guide


This way up


Fragile

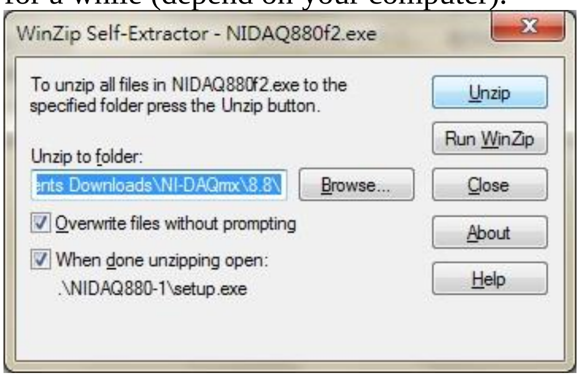

Keep dry


Keep off magnetic field

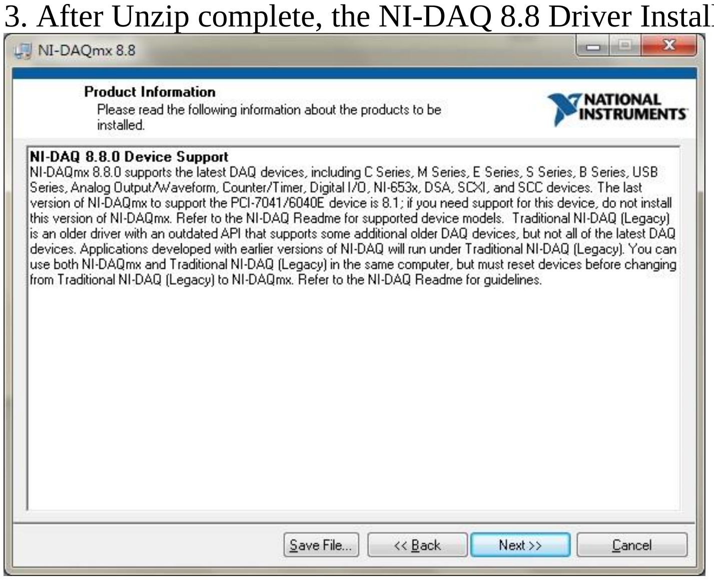
## Appendix D  Installation Guide of NI-DAQ Software

1. Double clicks NI-DAQmx8.8. The following figure will appear:

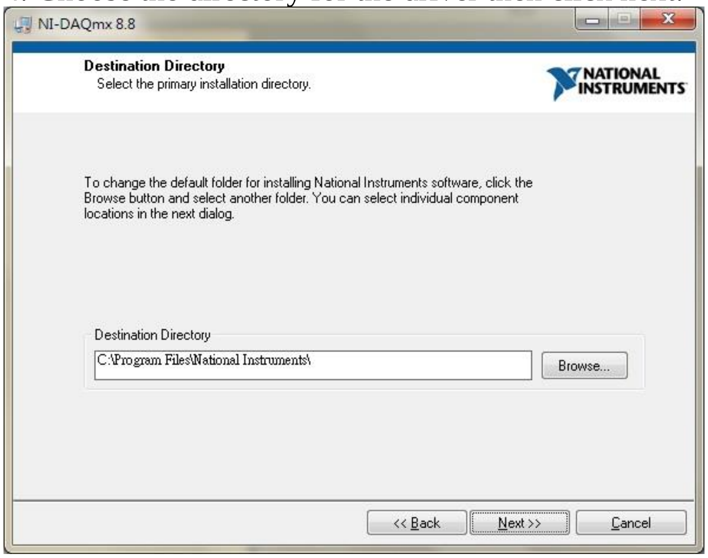

2. Clicks Yes (blue button) and WinZip will be launched. Run Unzip(Blue button) and wait for a while (depend on your computer).



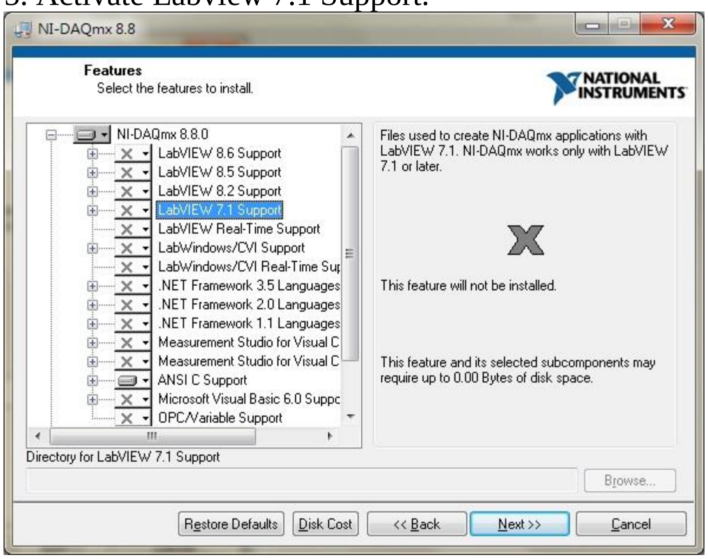

3. After Unzip complete, the NI-DAQ 8.8 Driver Installation will start. Click Next.



4. Choose the directory for the driver then click next.




5. Activate Labview 7.1 Support.

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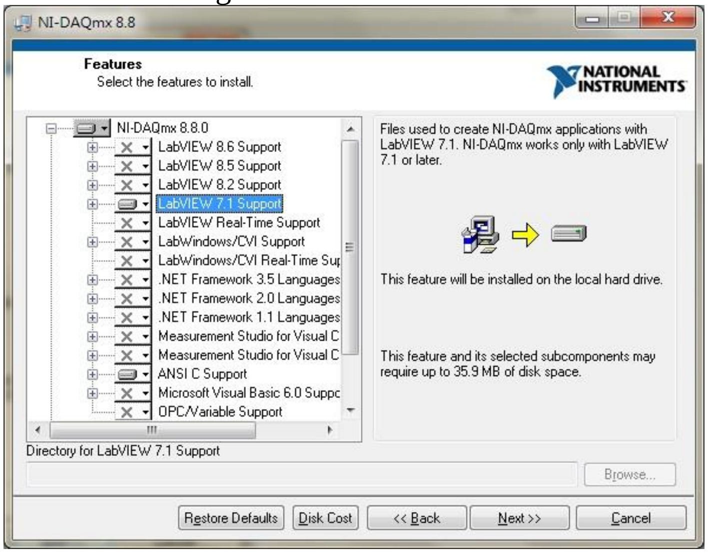
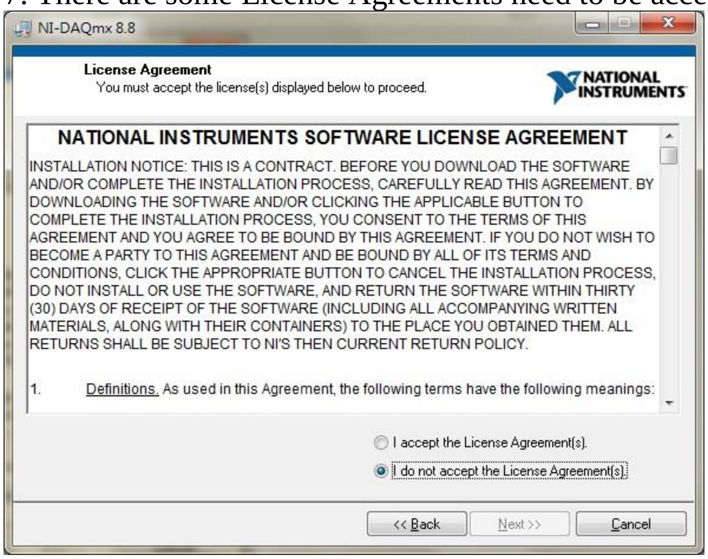
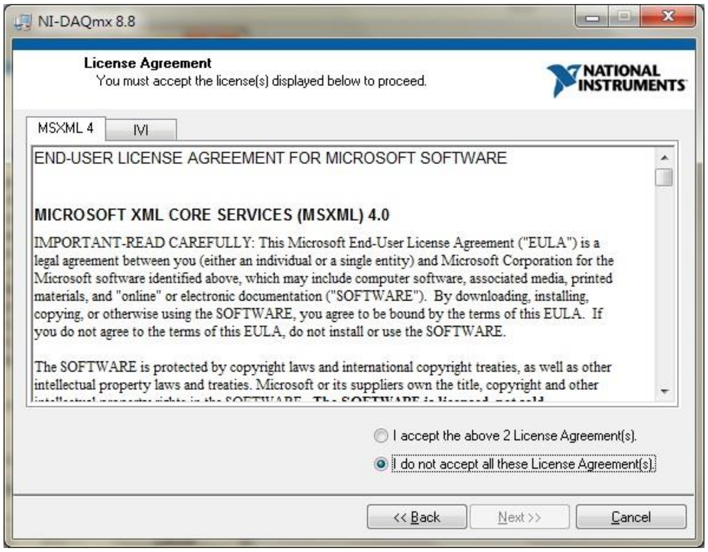
6. A hardware signature shows in front of Labview 7.1 Support button then click next.



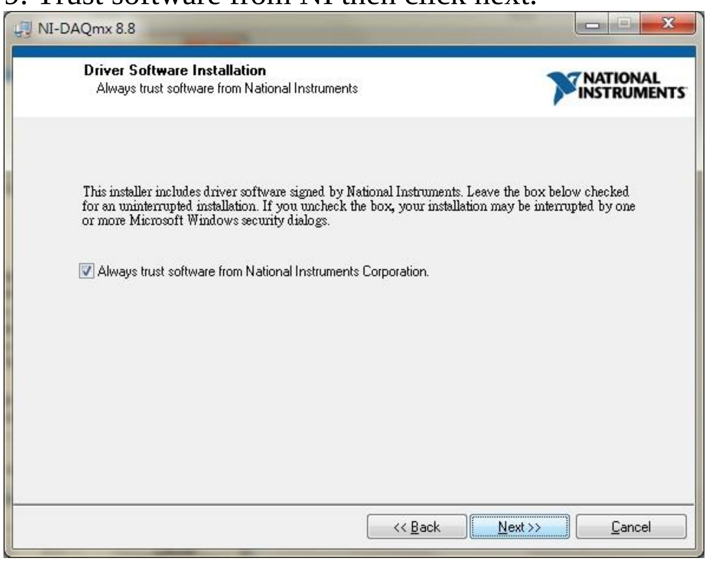

7. There are some License Agreements need to be accept. Confirm then click next.



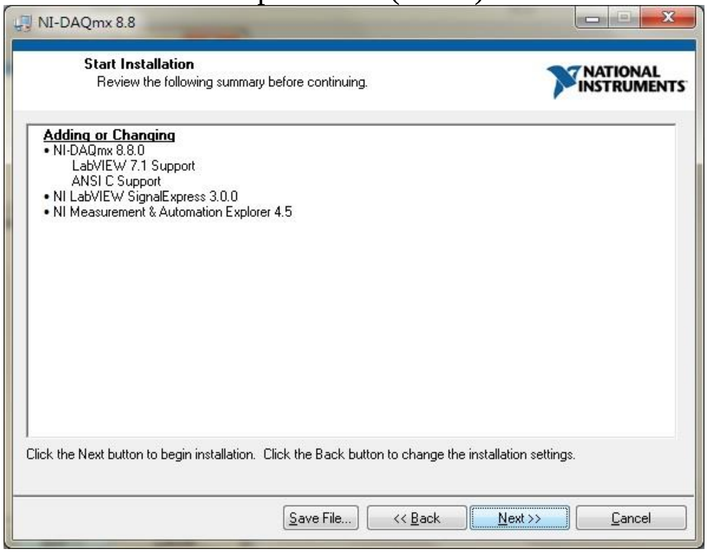
8. Another License for MSXML 4.0.



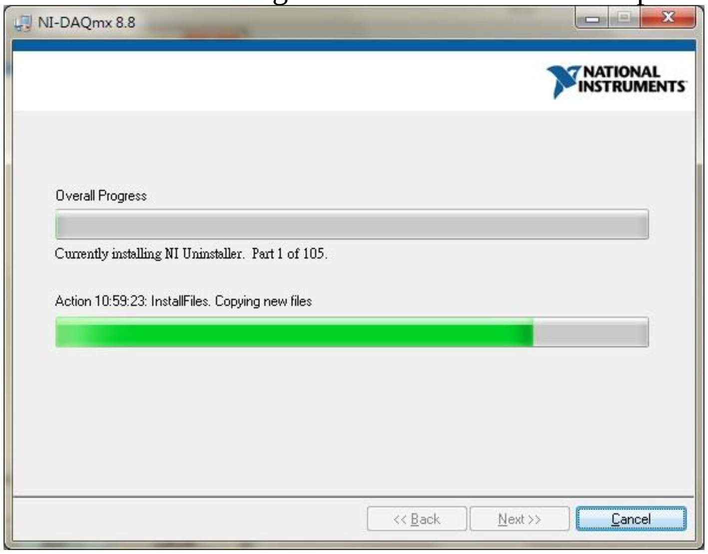

9. Trust software from NI then click next.



10. Confirm Labview 7.1 support, ANSIC support, SignalExpress, and Measurement and Automation Explorer 4.5 (MAX) are activated. Click next to Install.




11. Wait for Installing. The installation time is depending on your computer.





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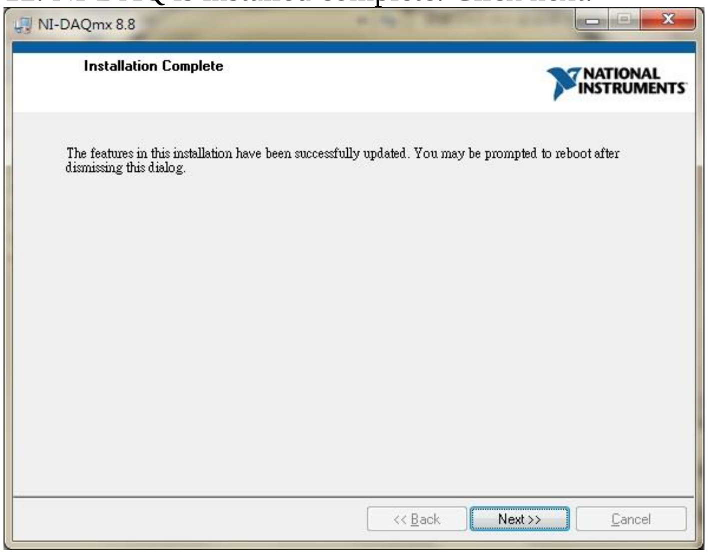
12. NI-DAQ is installed complete. Click next.




13. Restart your computer.


14. After connecting XacQuan to your computer, find MAX shortcut in your desktop. Double click it.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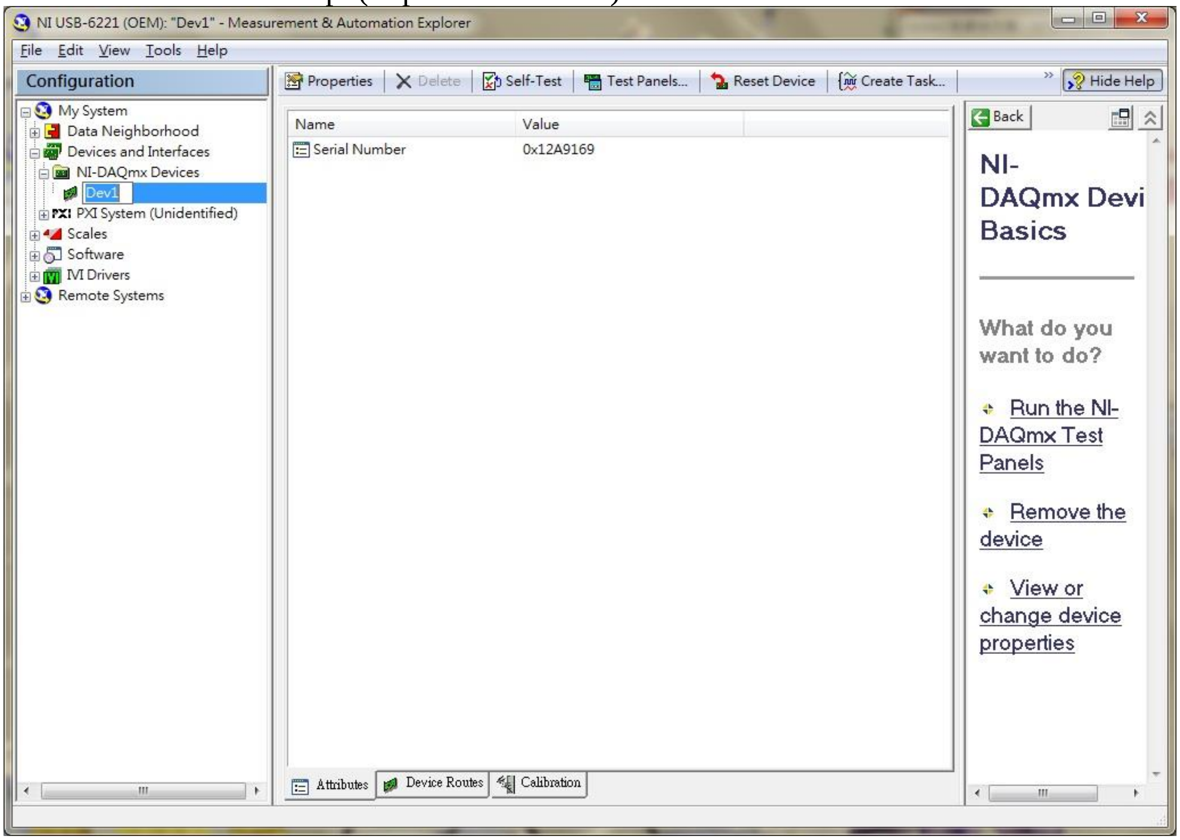
15. Check if a USB-6211 device is working on with the name is Dev1. If the name is not Dev1, please right click the device and rename it to Dev1. If nothing connects on, please contact NI for further help. (http://www.ni.com)





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