Preface

This book deals with theories and simulations of general dynamics, physics experiments using computers and analyses of experiments based on physics. This contains both theories and experiments and can be used in many fields' colleges of science and engineering, science high schools, education for the gifted children and so on.

The first chapter, *Data Logging and Analysis*, introduces the experiment and the data collecting process using sensors in Excel program and the analyzing process done by mathematical methods. In the second chapter, I explained the theoretical estimation and experiment analyzing process using physics modeling. The third chapter elucidates Newtonian mechanics and Lagrangian mechanics, which include velocity, acceleration, momentum, energy and law of energy conservation. The fourth chapter is about momentum, impulse and the average force and energy caused by impulse. The fifth chapter explains about oscillations - free oscillation, damped oscillation, forced vibration and shows deepened experiments.

Experiments in the chapter 3, 4, and 5 consist of estimations, processes, and explanations, analyses of experiments based on RTP and POE model. In the supplement, all experimental sheets conducted in this book are included so that they can be used easily in educational fields. The original codes of VBA program, experimental data and analyses of experiments in Excel can be read freely and applied to the education of physics and the analyses of experiments based on physics modeling.

The help and fervor of Dr. Lee Chang-hoon, Dr. Shim Jae-kyu and Mr. Kim Kwang-su were strong backings for writing this book. I also deeply appreciate Dr. Richard Beare, who visited to my lab from England, discussed physics experiment modeling using Excel, and shared opinions.

In the imagining and experimenting MBL lab,
Kim, Hyunsoo

1. Data Logging and Analysis

This chapter introduces the process of logging and analyzing experimental data in the worksheet of Microsoft Excel using Science Cube sensors.

1.1

Data Logging and Graph

This part is about installing MBL[1] software[2] as the add-in[3] for Excel[4] and finding out how to collect data using Excel. The physical quantity measured in Excel using sensors is recorded in the cells of worksheets. Graphs for the results analysis[5] can be drawn with chart magician or chart maker installed as added function, and it is possible to check out the graphs during the logging process by using charts already made in the worksheet.

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[1] MBL (Microcomputer-based Laboratory; Computer-based Laboratory) is used the same as Data Logging.

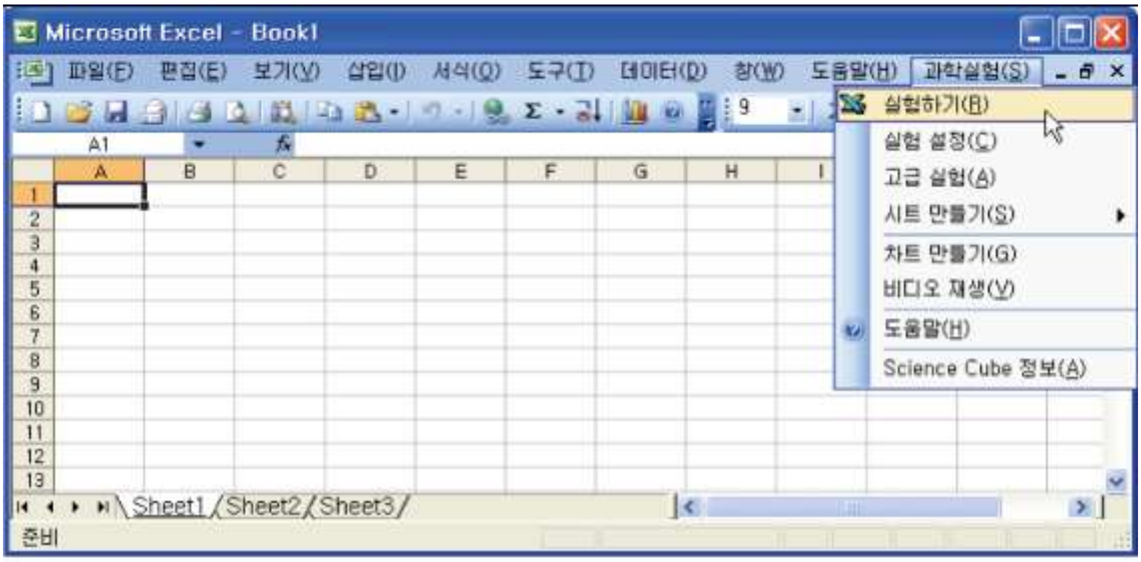
[2] This includes the estimation of physical quantity using sensors in the worksheet of Excel and the logging and analyzing of the data.

[3] Add-in can help to use not only the tools of Excel but also the functions set by users.

[4] In this book, Microsoft Excel student and teacher edition 2003 is used as a standard so this book is applicable to the low specification computers. Also, the functions of Excel 2003 can be used in Excel 2007.

[5] This book mainly uses scatter charts which can draw XY graphs.

1.1.1 Installation and Execution of MBL Software[6]



Picture 1.1.1 [Science Cube] menu installed in Excel worksheet menu[7]

Execute software CD or setup program downloaded from the web site to install MBL software as [Add-in] of Excel. As in picture 1.1.1 [Science Cube] has been installed in the menu[8] of Excel. Just as the picture 1.1.2, if you click the right button in the cell area of worksheet, the pop-up menu including [Experiment] and [Experiment Setup] appears and you can execute faster.

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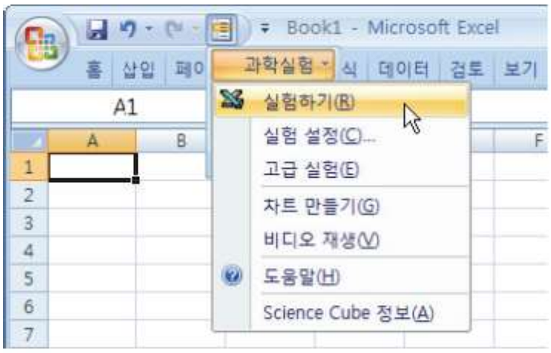
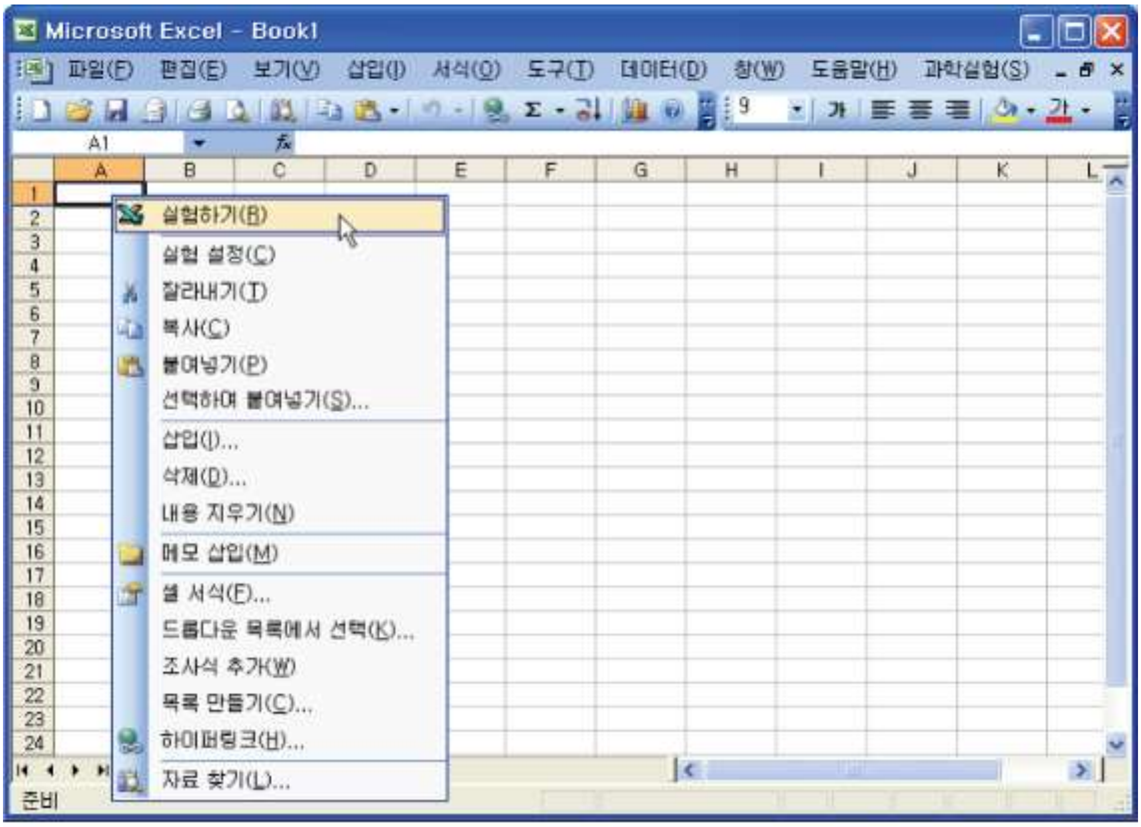
[6] You can download it at www.sciencecube.com and you need and a hardware such as MBL interface and sensors for data logging.

[7] 

Left is the picture of MBL software installed in Excel 2007. It is added in the worksheet menu as an add-in.

[8] In Excel 2007, the user can add [Science Cube] menu in [Add-in] menu to fast performance menu selectively.



Picture 1.1.2 opening [Experiment] pop-up menu in the cell area of worksheet: Click the right button of a mouse and open the pop-up.

1.1.2 Experiment in Excel

There are two ways of experiment and data logging, that is, RT (realtime)[9] experiment and NRT (none-realtime) experiment. The following is experiment with RT[10].

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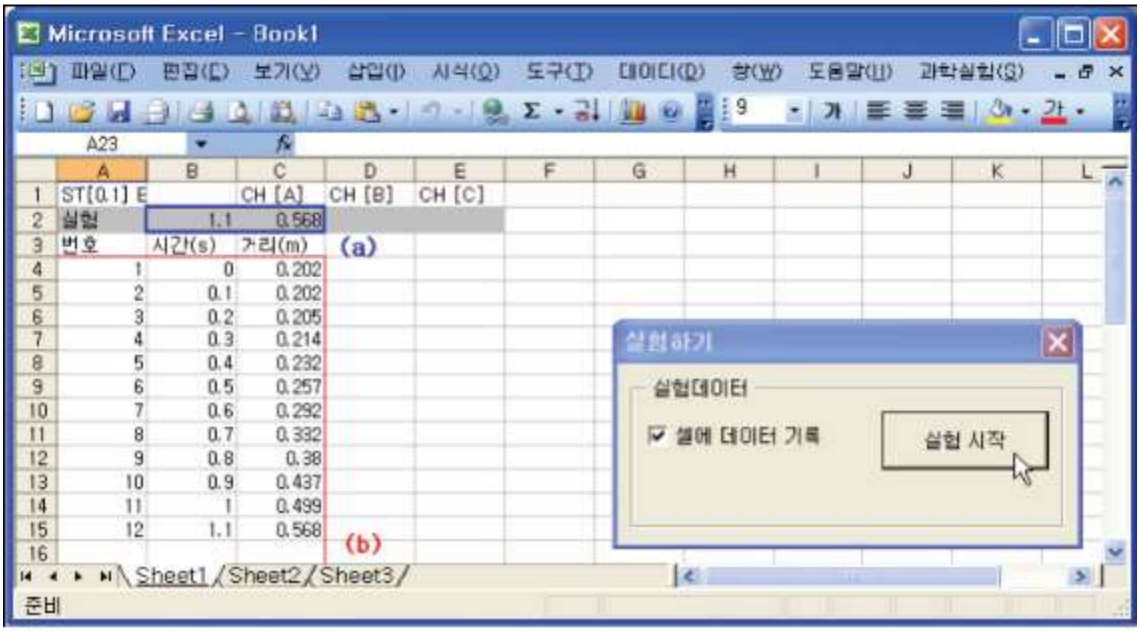
[9] RT experiment measures and records data at the same time when the interval is within 0.05 second, and when the interval is shorter, NRT is used.

[10] MBL interface should be connected with the computer beforehand. Sensor should be connected to the interface channel A, B or C. Generally, channel A is used with one sensor and channel B is used with two sensors.

a. Click [Experiment] in [Science Cube][11], then a small [Experiment] window will appear in the worksheet just as picture 1.1.3.

b. Click [Start Experiment], then MBL interface will operate and the measured data will be collected within the cells of row A, B and C just as picture 1.1.3 (b).

c. [Data Recording in Cell] is checked in [Experiment] window. If you cancel this, data will not be recorded in the cells. This is used when you check out the current measured data in cell B2, C2, D2 and E2 just as picture 1.1.3 (a)[12].



Picture 1.1.3 data logging in Excel[13]

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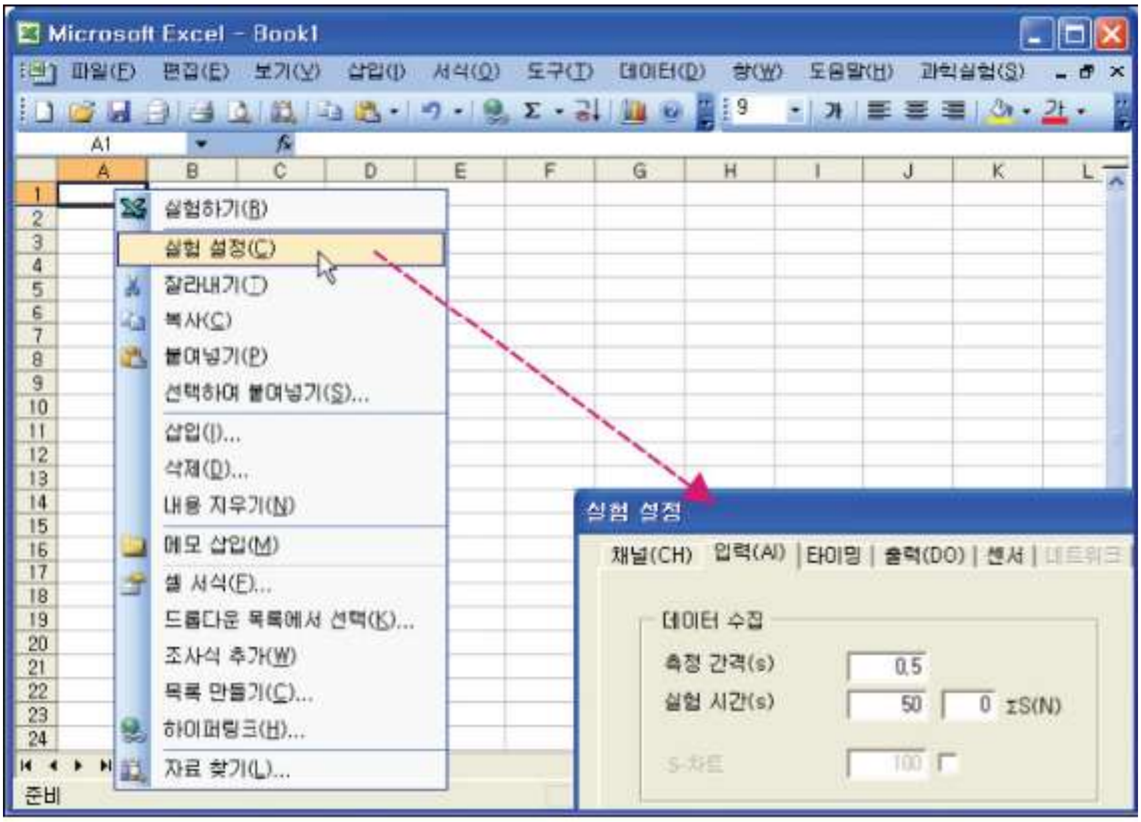
[11] This is added as [Add-in] in Excel worksheet menu. Instead of this menu, a toolbar menu consisted of icons can be used.

[12] Picture 1.1.3 is an example of the experiment connecting the sensor to channel A.

[13] Cell B2 represents the current estimating time, C2 the current measured data of channel [A], C3 of channel [B] and C4 of channel [C]. If data goes beyond the worksheet area, you can check out the current time and measured data at Cell B2, D2 and E2.

1.1.3 Experiment Setting

You can change the estimating interval, experiment time or the zero point of sensors in [Science Cube]-[Experiment Setting] menu. [Estimating Interval] in [Experiment Setting]-[Input] menu can set up the data collecting interval. [Experiment Time] sets up the time to collect data. When the time is up, the estimating stops automatically.



Picture 1.1.4 experiment setting: Setting up the estimating interval and experiment time according to the experiment

1.1.4 Graph Making

After the data logging, the result can be made as graphs[14] using the recorded data. If the experiment has been finished and the data has been recorded, close [Experiment] window.

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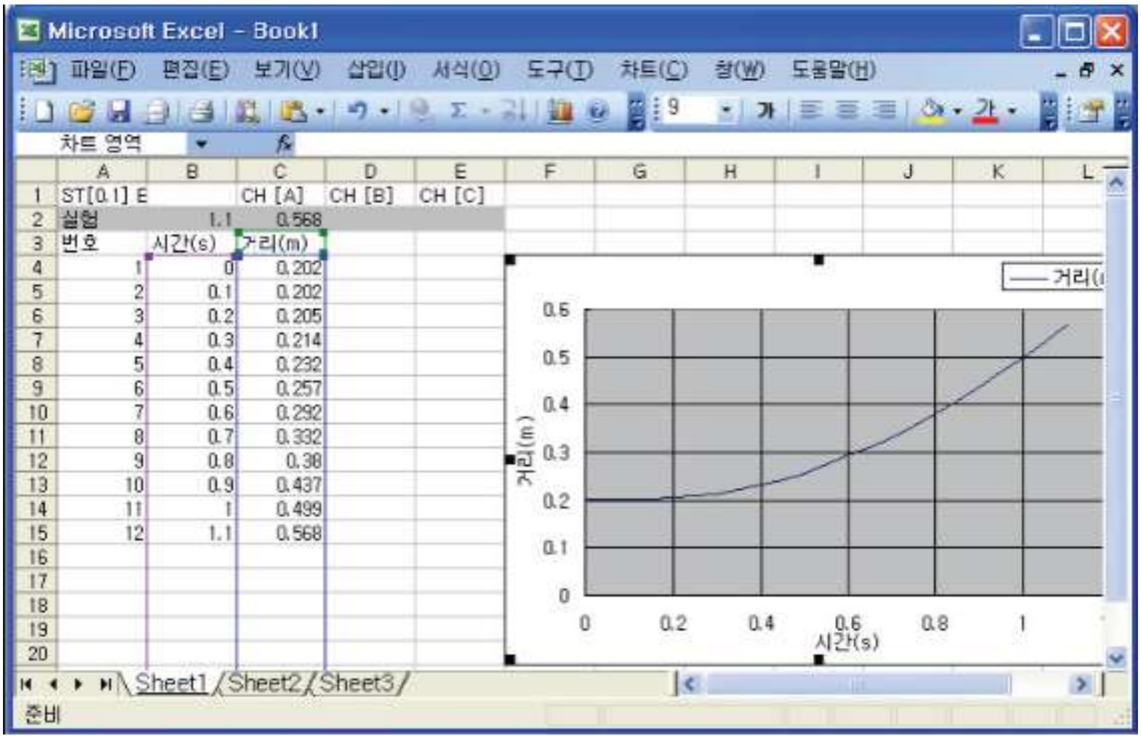
[14] You can use Excel chart magician

Click [Science Cube]-[Chart Making] and scatter charts[15] are made automatically[16].



Picture 1.1.5 scatter chart made automatically by [Chart Making]

Just as picture 1.1.5, after the chart has been made, you can modify the graph by changing [Cell Form][17] in cell area, or [Picture Area Form], [Data Series Form], and [Axis Form] in chart.

If you change [Picture Area Form], you can modify the frame and pattern of picture area. You can alter [Picture Area Form] when the picture area does not conform to the graph.

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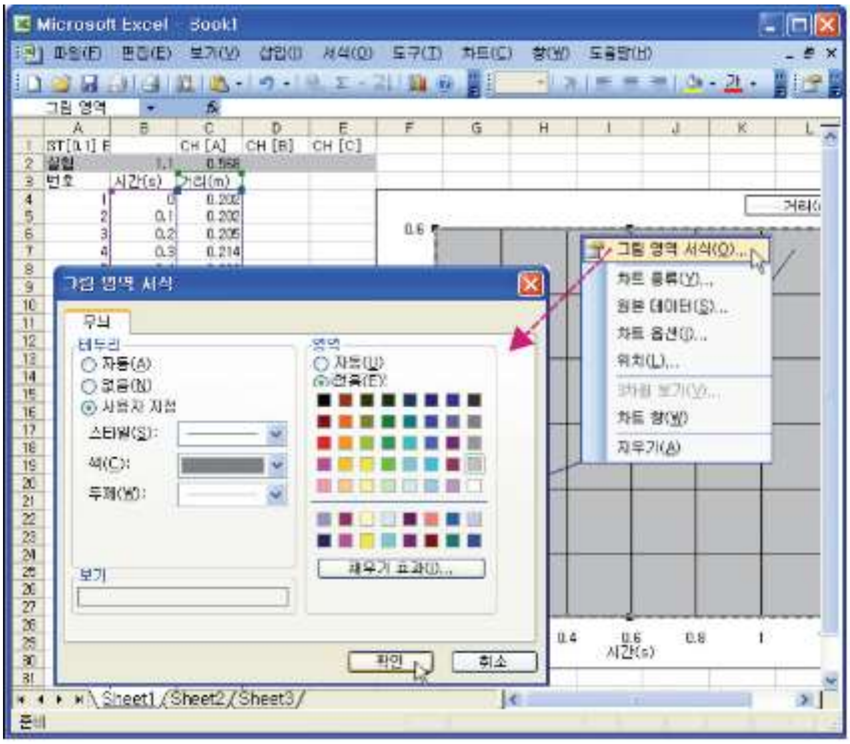
[15] Scatter chart is generally applied when analyzing physical quantities according to time(X axis).

[16] Data is collected in the series and drawn as graphs. For example, if you connect the sensor to channel A, time data is recorded in row B, distance data in row C. In the chart, X axis is row B and Y axis is row C.

[17] By changing the cell forms such as letters, numbers or signs, you can represent them with the graph. If the experiment is done in this worksheet, the data is recorded and the graph is drawn with the cell form.



Picture 1.1.6 changing [Picture Area Form]

If you modify [Data Series Form], data can be classified and font, color and representation can be renewed. The following is the process.

a. Choose the graph curve of data series[18], and then the range of series is shown in data cell area.

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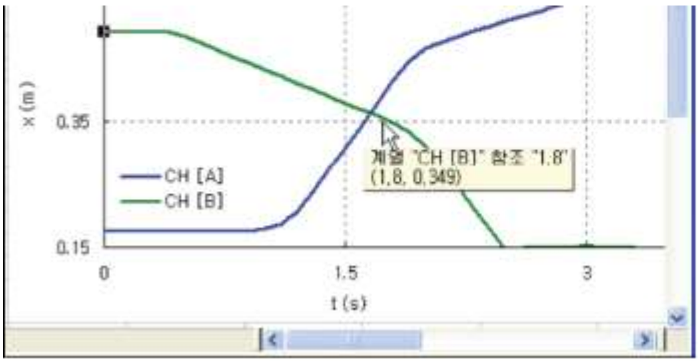
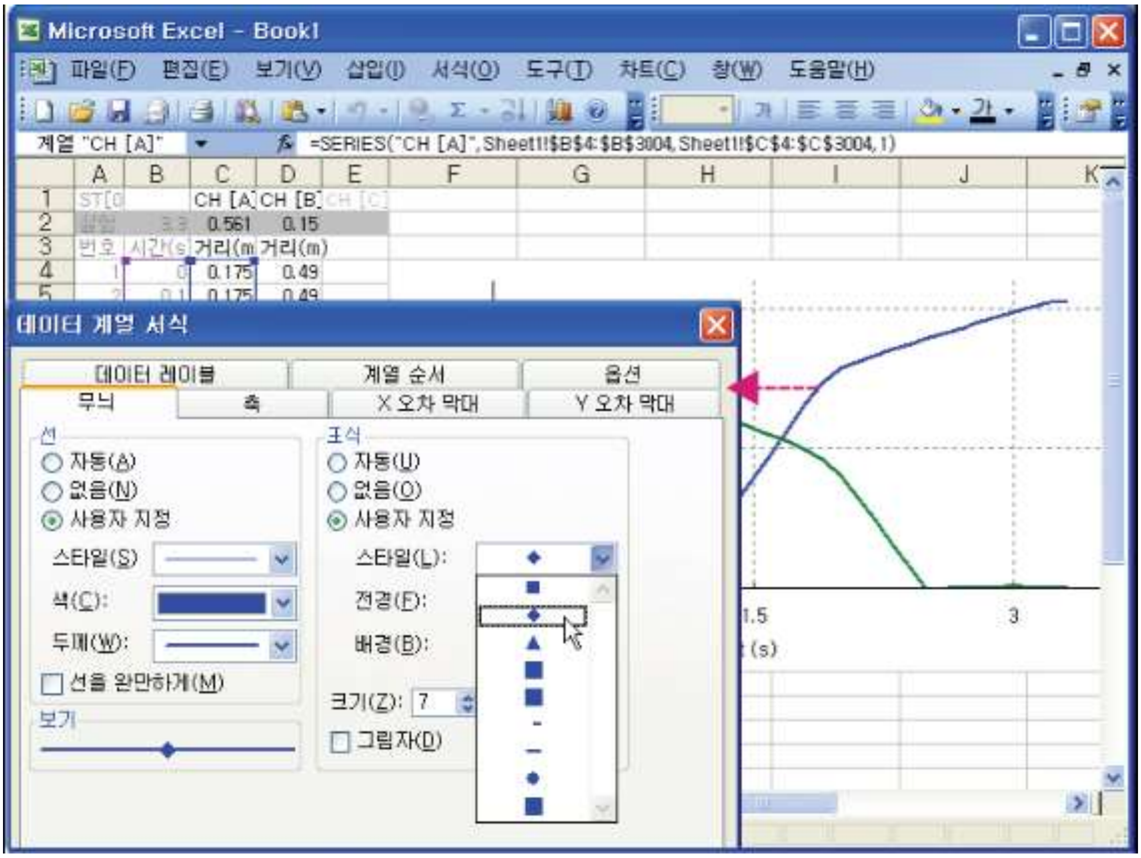
18 

If you put the cursor on the graph curve, the data series information and the quantities of X and Y axes are shown. Click the right button and you can choose [Data Series Form] just like picture 1.1.7.

b. Click the right button and choose data series form in pop-up menu, then you can change the pattern of the graph in [Data Series Form]-[Pattern].

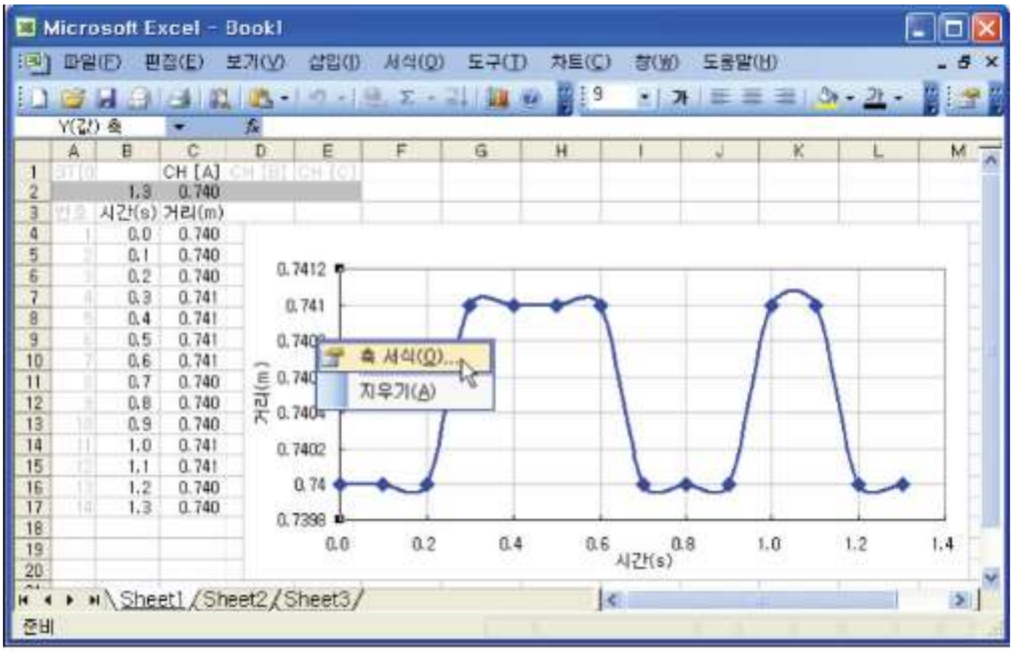


Picture 1.1.7 changing [Data Series Form]

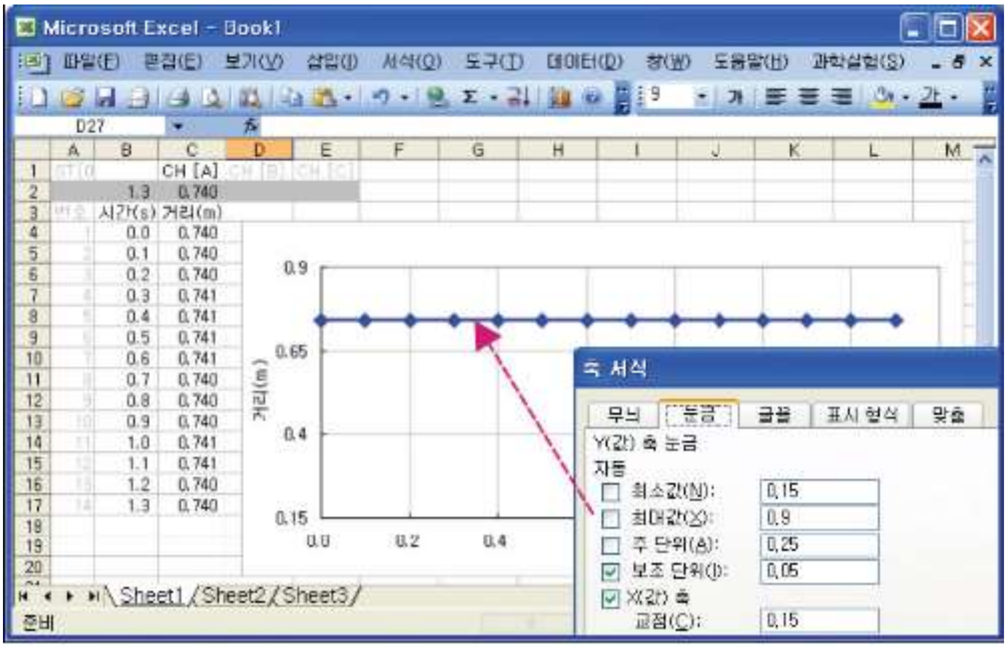
When the chart is made by [chart magician] or [Science Cube]-[Chart Making], the scale range of axis is set up automatically to the maximum and minimum quantities. But if you want to analyze the needed area only or draw the graph for the limited area, you can cancel the scale range and modify [Axis Form] as you want. The following is the process of modifying [Axis Form].

a. Put the cursor on the Y axis scale and click the right button, then [Axis Form] appears.

b. Change [Minimum] and [Maximum] so as to meet the need of the graph in [Axis Form]-[Scale].



Picture 1.1.8 the graph before modifying [Axis Form]



Picture 1.1.9 the graph after modifying [Axis Form][19]

[19] In picture 1.1.8, when the measurement value of distance is 0.740 and 0.741, although the numerical value is different, the measurement value is within the measurement error range. Therefore, the scale range of Y axis can be modified as 0.15 and 0.9m.

1.2

Mathematical Methods of Data Analysis

In 1.1, the process of data logging in Excel was introduced. The data is recorded within worksheet so it can be analyzed using many mathematical methods. One dimensional motion experiment in chapter 3 to 5 includes linear trend analysis, index trend analysis such as index curve predicted by index growth prediction, and differential and integral calculus. 1.2 deals with data analysis using function in Excel. Also statistic analysis of the data using analysis tools[1] of Excel is possible. This book mainly explains professional analyses needed in high physics experiments. In chapter 2, mathematical modeling using solution finding[2] function in physics experiment analysis will be explained.

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[1] [Tool]-[Data Analysis] or [Solution Finding] menu can operate high level mathematical, statistical data analysis.

[2] [Solution Finding] can be installed as [Add-in] in Excel.

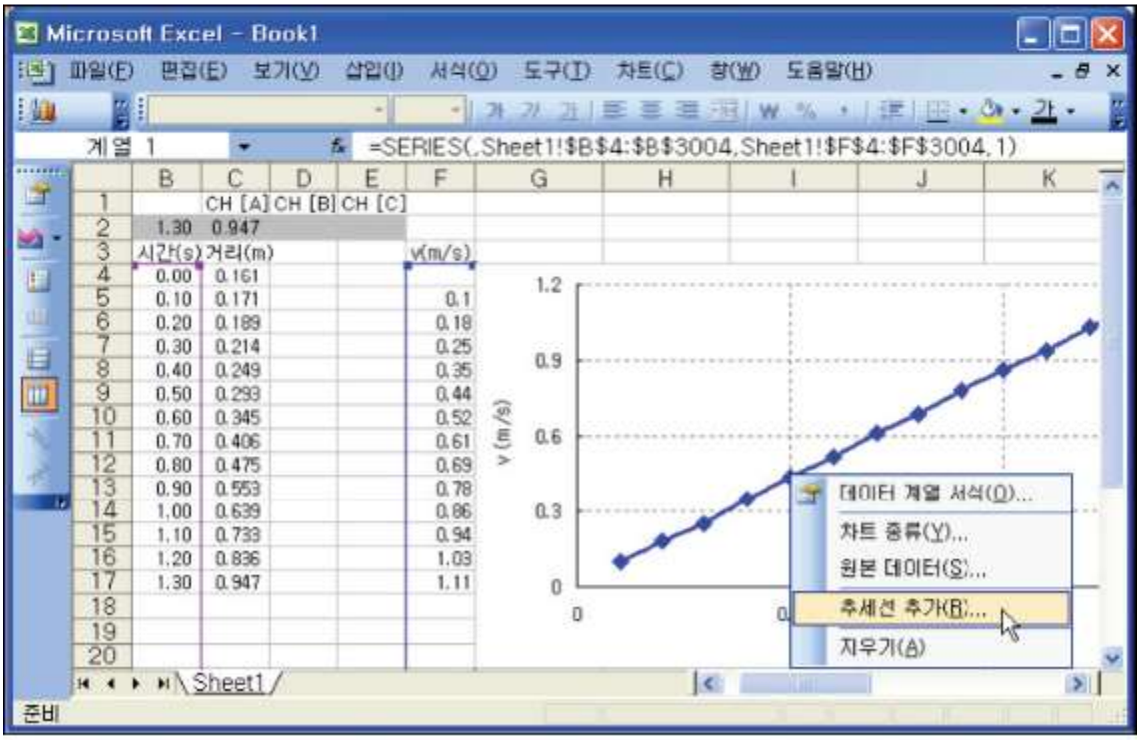
1.2.1. Linear Trend Analysis

In $x-t$, $v-t$ graph which is about an object's location x, velocity $v$and time t, the velocity or acceleration can be calculated easily by analyzing the gradient of the graph using linear trend analysis. The following is the process.

a. Put the cursor on the graph and click the right button as picture 1.2.1, then you can click [Trend Line Adding].

b. Choose [Linear] in [Trend Line]-[Type]-[Trend/Regression Type].

c. Choose [Show Formula on Chart] in [Trend Line]-[Option].



Picture 1.2.1 linear trend analysis: Choosing graph and clicking [Trend Line Adding]

Picture 1.2.2 is the result of adding linear trend line. The formula of the trend line is displayed on the chart and it can be calculated in the cells of worksheet by LINEST function[3].

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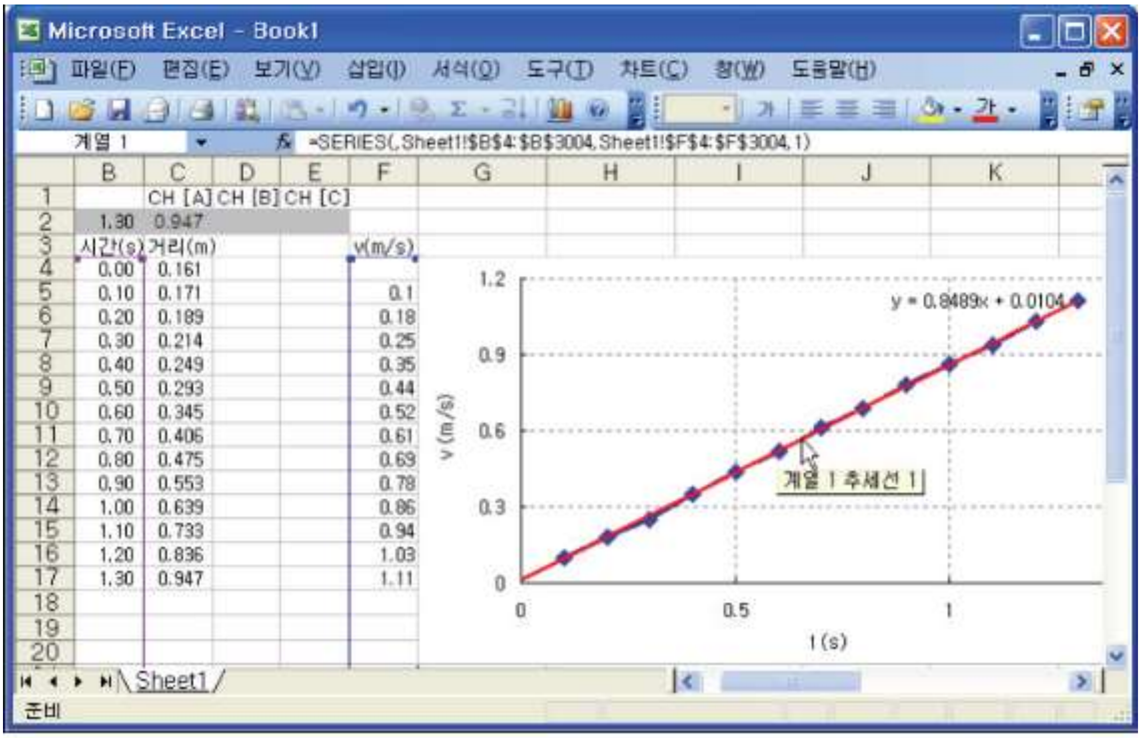
[3] The gradient and intercept are results of LINEST function. They can be recorded in the cell using INDEX function. For example, "=+INDEX(LINEST(F8:F17),1)" shows the gradient of the trend line from series F5 to F17, and "=+INDEX(LINEST(F5:F17).2)" shows the intercept.



Picture 1.2.2 linear trend analysis: Adding trend line and [Show Formula on Chart]

1.2.2 Index Growth Prediction and Trend Analysis

In v−$t$graph which is about an object's velocity $v$and time t, if the gradient of the graph is not a straight line, trend analysis on polynominal expressions (which is over quadratic equation) or index trend analysis is possible. For example, if the force applied to the object($F = bv$) is in proportion to the velocity, the velocity can be represented as index function like $v = v_0 e^{-Bt} + C$, so let's examine the index trend analysis. Picture 1.2.3 is v−$t$graph resulted from index trend analysis[4]. When the index trend analysis is not possible directly by [Trend Line Adding] because of intercept C, the following[5] is another way to analyze.

a. Record data of time t in row A.

b. Record data of physical quantity v, which should be analyzed, in row B.

[4] Index trend analysis is possible using mathematical modeling with [Solution Finding]. Consult to chapter 2.

[5] More detailed mathematical way is in chapter 5 Oscillation.

c. Record the value of GROWTH (v) in row C.

d. Determine the value of | GROWTH (v1)-v1 | as intercept C[6].

e. Record the value of v+ C in row C.

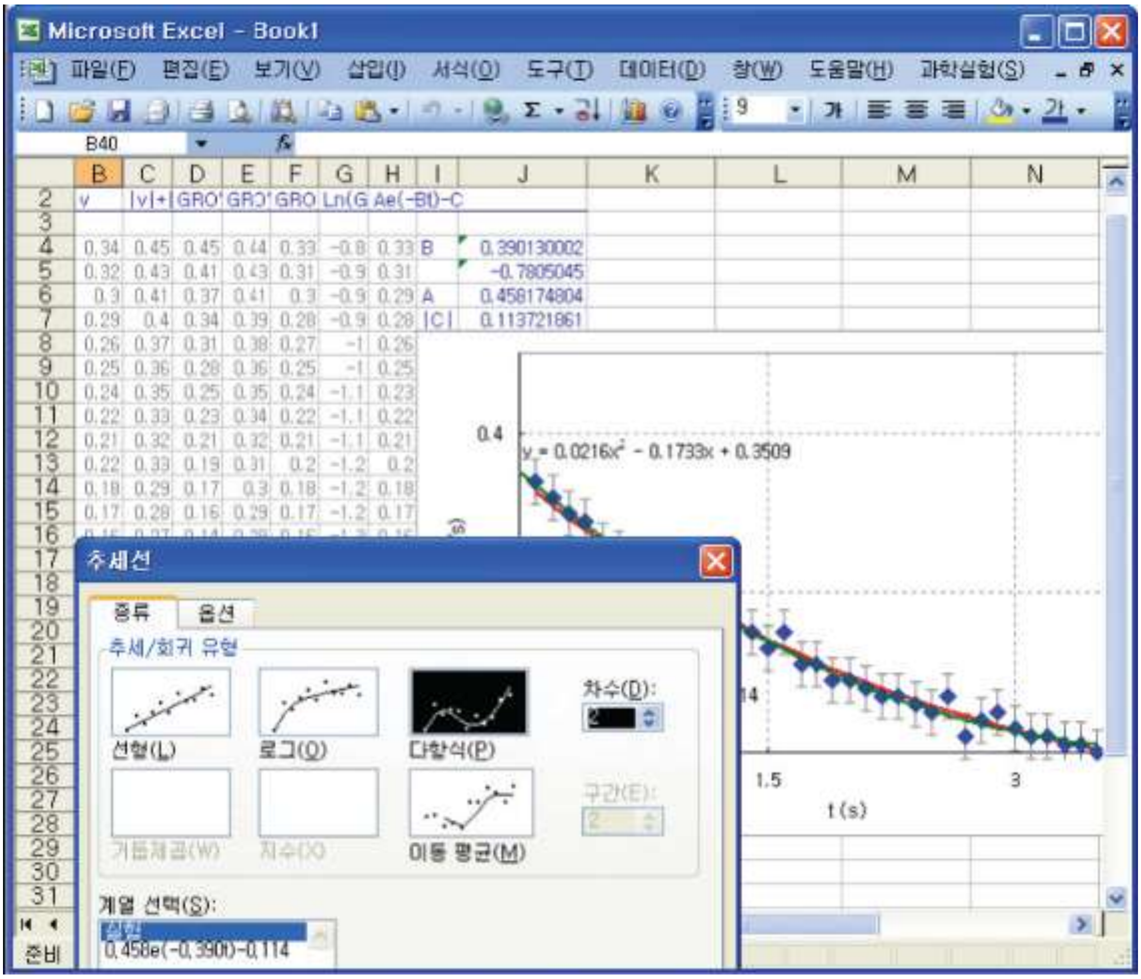
f. Record the value of GROWTH (v+ C) in row E.

g. Record the value of GROWTH (v+ C)-C in row F.

h. Record the value of LN (GROWTH (v+ C)) in row G.

i. Calculate coefficient B with "=+ INDEX (LINEST (G4:G38,A4:A38),1)". G4:G38 is the range of data, A4:A38 is the range of time data.

j. Calculate coefficient A with "=+ EXP (INDEX(LINEST(G4:G38,A4:A38),2))".



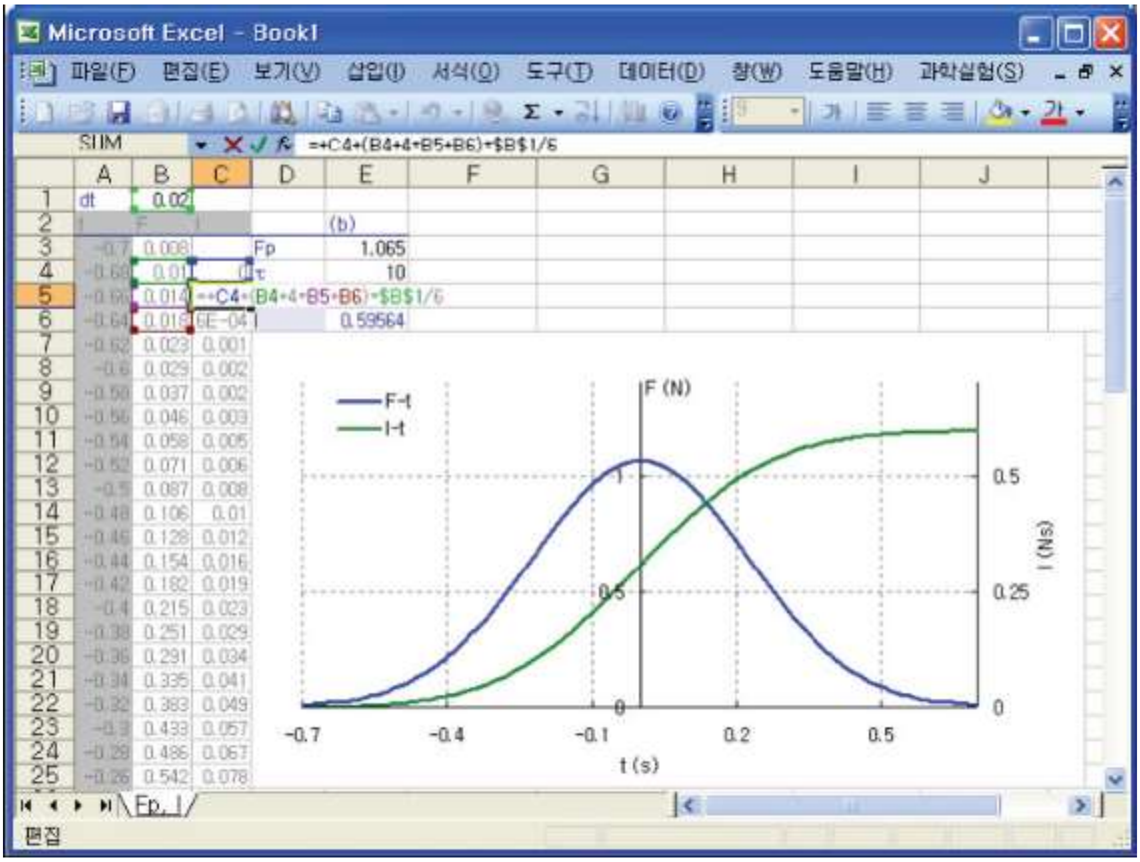
Picture 1.2.3 trend of quadratic equation and v-$t$graph drawn by index trend analysis

[6] This way might not be appropriate according to the experiment data. Then use mathematical methods to calculate the value of intercept C. More detailed information is in chapter 5.

1.2.3 Differential and Integral Calculus of Data Series

If a certain data series corresponds to the equation of motion which can be represented as the differential of time, it can get the value of integral calculus by solving ordinary differential equation (ODE[7]). ODE applies the 4th Runge-Kutta(RK) method[8]. For example, the area of F-t graph about the force applied to the object, F, and time t is the value of integrating F-t graph, and corresponds to the impulse.

Input the formula of RK$f_{n+1}(h) = f_n(h) + h(k_1 + 2k_2 + 2k_2 + k_4)/6$ successively to the row of worksheet[9], then the value of the integration will appear at the cell which locates at the end of data series.



Picture 1.2.4 I-t graph resulted from F-t graph integration: the value of I-t graph corresponds to the value of integration.

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7 If the equation of motion is like $m\ddot{x} + kx = 0$, you can get x, v by solving quadratic ODE(Ordinary Differential Equation). More detailed information is in chapter 5.

8 The mathematical explanation of the 4th RK is in chapter 5.

9 For example, input like "=+C4+(B4+4*B5+B6)*B$1/6". If f(h) is a known function, you can calculate like $f_{n+1} = f_n + h(k_1 + 4k_2 + k_3)/6$.

The curve of F-t graph and I-t graph in picture 1.2.4 are in chapter 5. Let's take an example of integration using RK. Integrate standard normal distribution[10] curve and prove it by compare the result with NORMDIST function of EXCEL[11].

	A	B	C
	t	F(t)	I(t)
4	-0.68	0.01045	0
5	-0.66	0.01366	=+C4+(B4+4*B5+B6)*$B$1/6
6	-0.64	0.01772	=+C5+(B5+4*B6+B7)*$B$1/6
7	-0.62	0.02289	=+C6+(B6+4*B7+B8)*$B$1/6
8	-0.60	0.02910	

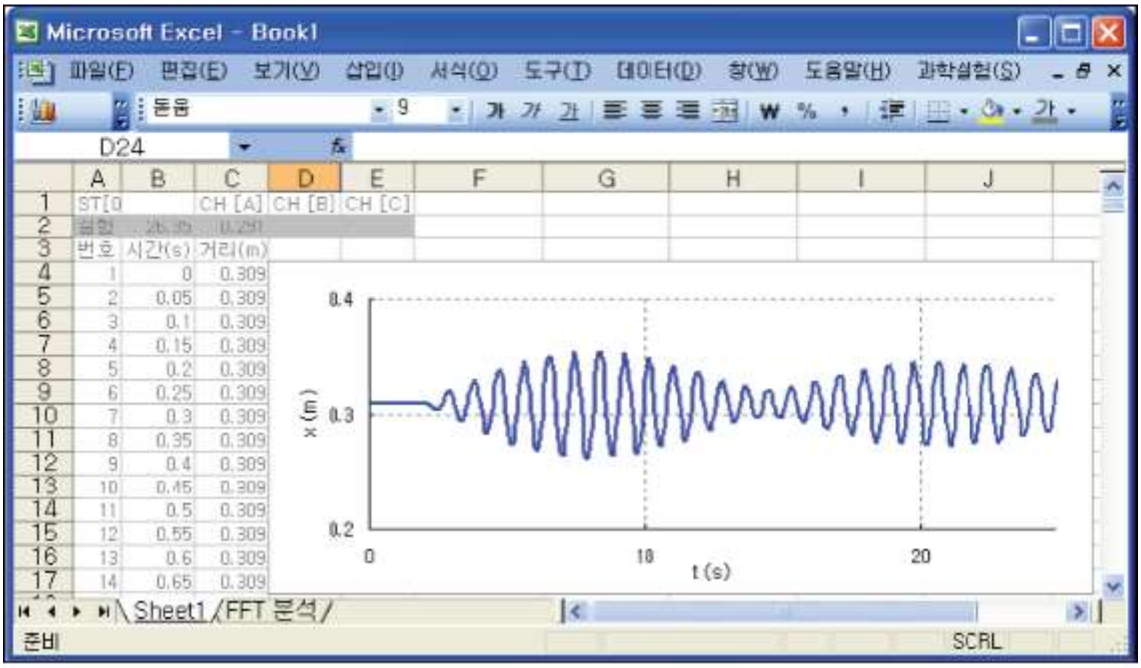
Table 1.2.1 example of the 4th RK formula input: dt is recorded in the cell as a consistent value (B!=B5-B4). If f(t) is already known, input (B4+ 4*B5+ B6), and in the case of experiment data, calculate as (B4+ 2*B5+ 2*B6+ B7).

10 $f(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}, (\mu = 0, \sigma = 1)$

11 NORMTDIST function is the same as "=+ NORMDIST(x,mean,standard_dev,cumulative)". in the case of mean=0, standard_dev=1, cumulative=TRUE, NORMSDIST function, which is standard normal distribution, appears. Therefore you can see the integration result of standard normal distribution curve.

1.2.4 Spectrum Analysis in Frequency-domain

In physics experiment, analyses using fast fourier transform(FFT[12]) are very important to learn high level of physics experiment. FFT analysis is usually done by professional programs because of complex mathematical calculation or in a situation when the analysis should be done very quickly. Here is the easy FFT analysis in the way of NRT[13] using VBA of Excel. Next is the example of amplitude spectrum analysis[14] within frequency-domain.



Picture 1.2.5 $x-t$ graph in sheet 1

[12] FFT(fast fourier transform): this is used to analyze the spectrum of amplitude within the frequency domain, such as sound spectrum analysis.

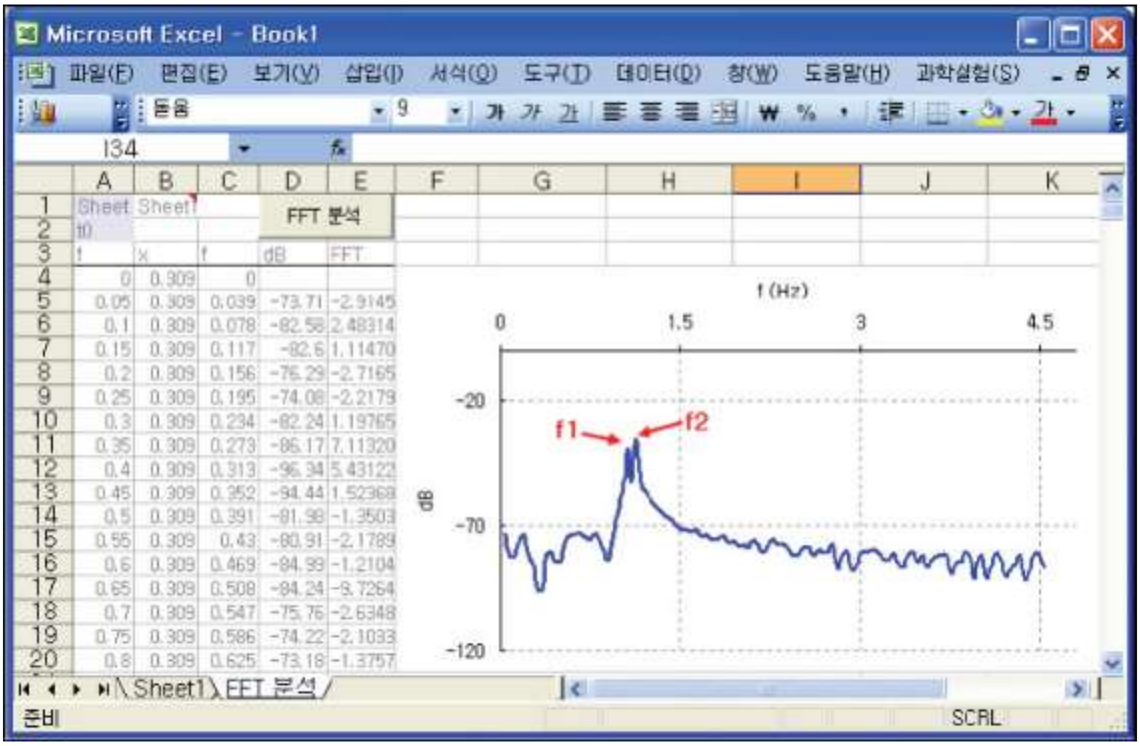
[13] NRT(none realtime): When collecting data by NRT, certain amount of data is stored in the memory and read. On the contrary, RT(realtime or realtime point) collects data at the same time such as PTP(point by point). RTP(realtime physics) uses RT and NRT as teaching-learning model using computer. Strictly speaking, RT used in RTP is not a realtime point.

[14] Chapter 5 introduces the way of analyzing frequency of a cart using FFT analysis. The cart is in a transient state during forced vibration.

Picture 1.2.5 is the result of forced vibration experiment about a cart in a transient state. $x-t$ graph shows the changing phase of the amplitude $x$including two frequencies. This is similar to beat phenomenon[15].

	A	B	C	D	E
	t	x	f	dB	FFT
4	0				
5	0.05				
6	0.1				
...					

Table 1.2.2 screen design for FFT analysis in Excel

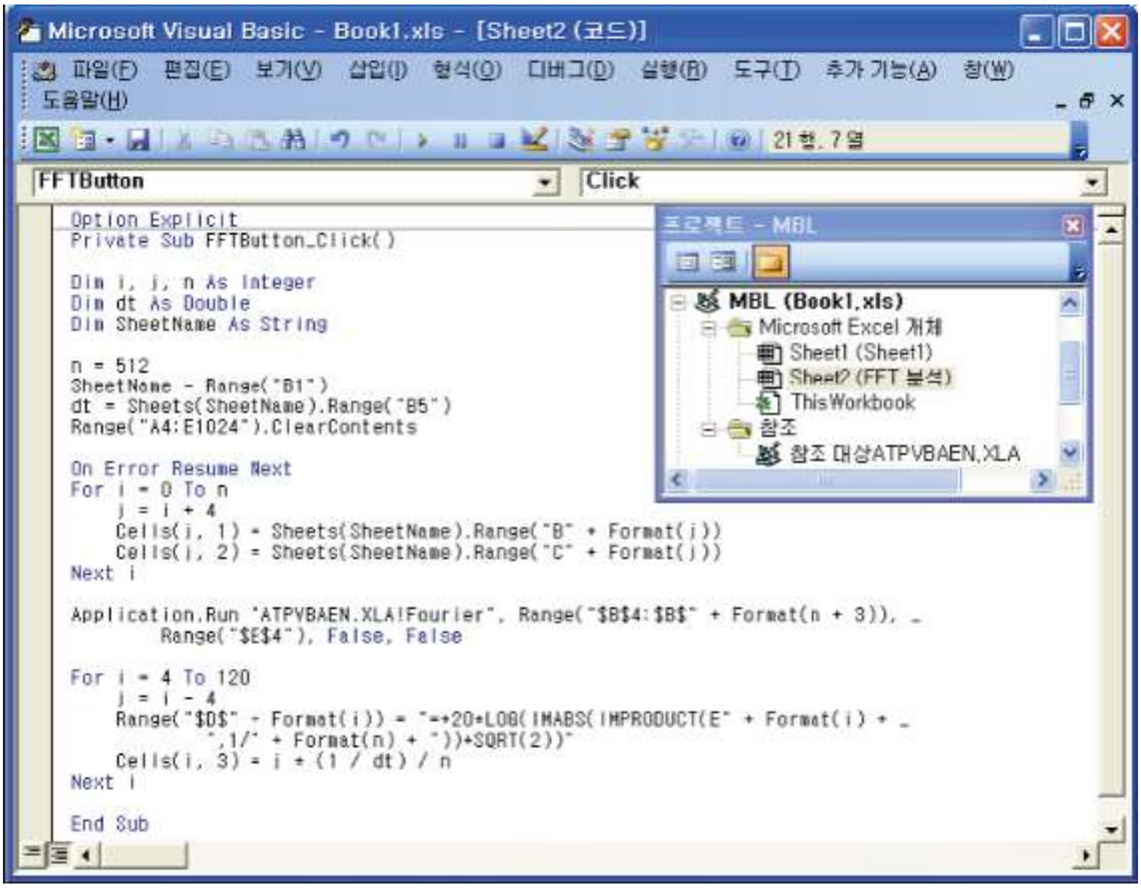


Picture 1.2.6 spectrum of frequency-amplitude analyzed in "FFT analysis" sheet

[15] beat phenomenon: a physical phenomenon caused by the reiteration of two adjacent frequencies. beat frequency $f=|f_2-f_1|$

In table 1.2.2 the screen is designed so that the result of FFT analysis is recorded in row E, and dB calculation value using row E[16] in row F. Picture 1.2.6 is the graph of FFT analysis.

In picture 1.2.6, the experiment data is brought from sheet 1 and recorded in row A and B. In row C, D and E, the result of FFT analysis using [FFT Analysis] button in Excel VBA[17] is recorded. Picture 1.2.7 shows VBA original code of [FFT Analysis] n picture 1.2.6.



Picture 1.2.7 screen of VBA original code setting in "FFT analysis"

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[16] The result of FFT analysis is recorded in a complex number like a+bi. To calculate this in dB(decibel) scale, apply a normalized calculation formula such as "=20*LOG(IMABS(IMPRODUCT(E5,1/512))*SQRT(2))".

[17] If VMA button is in Excel, data analysis can be done easily when doing successive works of diverse formula or applying complex mathematical methods. The example of VBA setting and applying is in chapter 5. Consult the download sites of the supplement for Excel file and VBA original code used in this book.