The Application of LabVIEW for Data Acquisition at an Accelerator Laboratory.

J A Clarke and P A McIntosh
DRAL Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK.

Abstract

LabVIEW® is a commercial high level graphical programming language that is designed for data acquisition and control. This package is now used extensively on the SRS at Daresbury in a wide range of aspects of measurement from component testing to beam monitoring. This paper discusses the applicability of LabVIEW and demonstrates its utility by illustrative examples, including measurement of beam profiles, BPM Calibrations and RF Cavity Testing.

1. INTRODUCTION

All accelerators throughout the world use computers for routine data acquisition. This may be for monitoring beam current, vacuum parameters, magnet currents, etc. At Daresbury the logging of machine parameters is carried out by the main control system but it is found that for component testing or for accelerator physics experiments a stand-alone system based on a microcomputer is preferable. Almost all on-line diagnostics and hardware tests are now carried out using software called LabVIEW. This paper describes the main features of this software and discusses its potential usefulness throughout the accelerator community by using illustrative examples.

2. LABVIEW OVERVIEW

2.1 Basics

LabVIEW is a commercial, high level, graphical programming language that is designed for data acquisition, analysis and control [1]. It has an unusual programming methodology, in that software modules are *graphically linked.* These modules are roughly equivalent to a subroutine in a conventional text based language except that each one is itself fully executable. The graphical approach provides an intuitive understanding for how the program is structured and offers far greater flexibility for alteration. The LabVIEW package runs on Macintosh, PC or Sun systems and code is fully interchangeable between these platforms.

Every module of the software is called a Virtual Instrument (VI). These are the building blocks for every program. Basically, every VI consists of two windows: the first is called the *block diagram* which is where the code is held and edited and the second is termed the *front panel* which is the interface with the user. Perhaps the best way to illustrate the fundamentals of the program is with a simple example. Calculating beam lifetime is common to many accelerators. This example measures the beam current N times via an ADC and then fits the data to an exponential decay to derive the lifetime. The block diagram for this simple algorithm is given in figure 1. Between each reading the VI waits for a fixed amount of time. This timebase is then used for the curve fit. The general form of the exponential fit used is given by:

$$I(t) = I_o e^{bt} \qquad (1)$$

The beam lifetime in seconds is equal to -1/b.

The user sees the front panel which is clear and concise, it is a simple matter to include graphical output such as knobs, meters, switches or scope displays. It is also possible to import your own drawings so that the front panel can be made to look like the measurement system itself. This degree of freedom ensures that the user intuitively understands how to run the program.

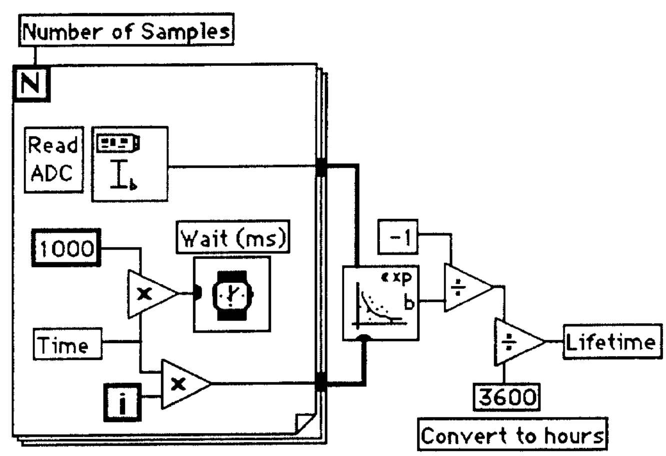

Figure 1. LabVIEW code for calculating beam lifetime.

2.2 Facilities

One of the great advantages with LabVIEW over traditional programming languages is the ability to quickly look at an unfamiliar VI and to be able to understand the execution of the program. This is due to the graphical representation of the code which means that generally all of the program fits onto one screen, so tracing paths of variables etc is trivial. This ability is greatly enhanced by the debugging facilities available. The code continually checks VIs as they are edited to see if they are able to be compiled. If an error is detected, such as passing on the wrong data type, then this will be highlighted until it is rectified. However, as is more usually the case, if the VI will run but gives the wrong result then very sophisticated debugging routines are available. For example, it is possible to highlight each part of the VI as it executes and to literally watch the data being passed on to the next part of the program. As it does this each wire displays exactly what value it is passing. Due to these tremendous facilities it is very unusual not to have the most sophisticated program fully debugged in less than an hour.

2.3 VI Libraries

National Instruments operates an 'open' policy with regard to distribution of specialist VIs. This means that it usually distributes freely VIs that have been written by themselves or by others. So, for example, a huge library of routines covering data analysis, digital signal processing, graphing, network communication, etc., are available. More important perhaps, are the VIs that have been written for particular pieces of hardware. Literally hundreds of well known oscilloscopes, meters, function generators, etc., already have VIs that are freely available from National Instruments or can be downloaded via the Internet. By using these VIs it is possible to have a piece of hardware communicating sensible data within minutes. These VI libraries have been used extensively at Daresbury without mishap and have probably saved months of effort.

3. EXAMPLES

3.1 Measurement of Beam Profiles

At Daresbury there is a dedicated 2 GeV electron storage ring for synchrotron radiation research. One of the main parameters that determines the photon beam quality is the electron beam size. This is measured at Daresbury using the visible synchrotron radiation on a diagnostic beamline [2]. The photon beam is focussed onto linear photodiode arrays that are connected to an oscilloscope. The general scheme is presented in figure 2. The Macintosh computer runs LabVIEW which controls the scope. The program will capture the scope traces and fit Gaussian profiles to them. It will derive the beam size and save it into a specified file. Typically this program will measure both the horizontal and vertical profiles once every 2 minutes for 24 hours. The VI is extremely user friendly to run and only requires the user to input two parameters; the time between samples and the number of samples.

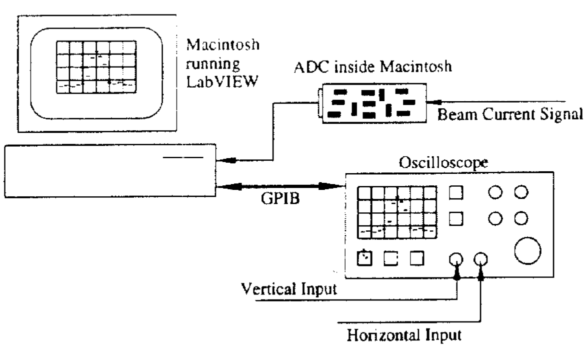

Figure 2. General scheme of beam profile monitors.

3.2 Beam Position Monitor Calibrations

New BPM electronics has been employed at Daresbury, which has been designed to be able to detect relative electron beam position movements with a resolution of <10 μm [3]. The new modules utilise the principle of down conversion and low frequency detection. Sum and difference (Σ and Δ) signals are input from the BPM pickup buttons and are mixed with a local oscillator (LO), to produce a 500 kHz intermediate frequency (IF). Synchronous low frequency detection is then performed on the IF signals to produce Σ and Δ DC signals. A calibration measurement is then performed on each channel of the low frequency detector to eliminate any offsets inherent in the measurement process, producing Σ_{cal} and Δ_{cal} signals. From these four signals, a figure for relative beam position can be found using the following equation;

$$\text{Relative Beam Position (mm)} = \frac{\Delta - \Delta_{cal}}{\Sigma - \Sigma_{cal}} \qquad (2)$$

LabVIEW was used to commission all 16 horizontal and vertical channels prior to installation on the SRS. Five instruments are controlled by LabVIEW across a General Purpose Interface Bus (GPIB or IEEE 488.2), providing Σ and Δ input signals which are swept over a 50 dB range. Two 5 1/2 digit Digital MultiMeters are controlled which acquire the Σ, Δ and Σ_{cal} and Δ_{cal} output signals. A programmable power supply is used to switch each channel into calibration mode; LabVIEW then stores all the relevant input and output values in spreadsheet format on the Macintosh computer for analysis later if required, whilst also interactively plotting response curves of input amplitude (dB) against relative position (or Offset (mm)). Figure 3 shows the test results for one of the BPM's. This particular one showed that for a 32 dB range, the deviation in offset was in the order of 10 μm.

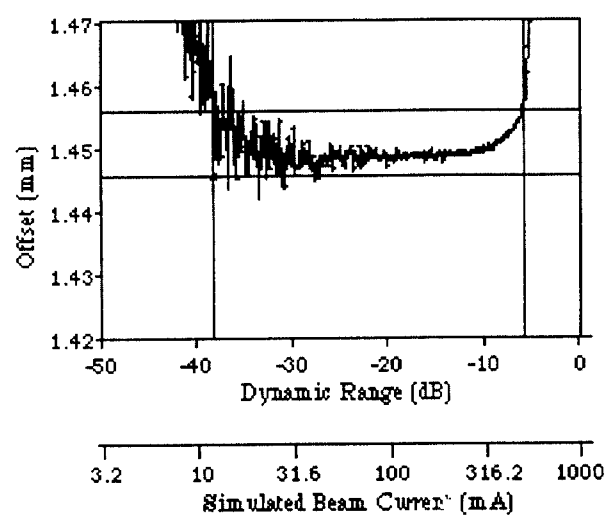

Figure 3. Simulated beam position as a function of current using LabVIEW.

3.3 RF Cavity Testing

Perturbation measurements are performed on RF cavities to evaluate Ro/Qo, which is the *relative effectiveness* of an accelerating structure, and consequently Shunt Impedance (Ro), which is a figure for the impedance of an RF cavity at resonance [4]. Perturbation measurements involve drawing a perturbing object (usually a bead, with radius r, permittivity ε) through the central beam pipe of the cavity whilst monitoring the cavity's resonant frequency as the object travels its entire length. The bead perturbs the stored energy of the resonant system by a very small amount, which results in a small shift in the resonant frequency (Δf). This frequency shift is related to the relative E-field and H-field strengths in the area of the bead. The equation used to solve R_o / Q_o for an accelerating cavity is derived from Slater's Perturbation theory [5] and normal tuned circuit theory and is expressed as;

$$\frac{R_o}{Q_o} = \frac{1}{\pi r^3 \omega_o \varepsilon}\left[\int_0^L \sqrt{\frac{\Delta f(l)}{f_o}}\,.dl\right]^2 \qquad (3)$$

Where R_o = Uncorrected Shunt Resistance (or Impedance at resonance) (Ω)

Q_o = Unloaded Q factor of the cavity

ω_o = Unperturbed resonant frequency (rad/s)

ε = ε_o if using a metallic bead

= 8.85×10^{-12} F/m, else

$\varepsilon = \frac{(\varepsilon_1 - \varepsilon_2)\varepsilon_o}{(\varepsilon_1 - 2\varepsilon_2)}$

ε_1 = dielectric constant of medium filling cavity

ε_2 = dielectric constant of the bead

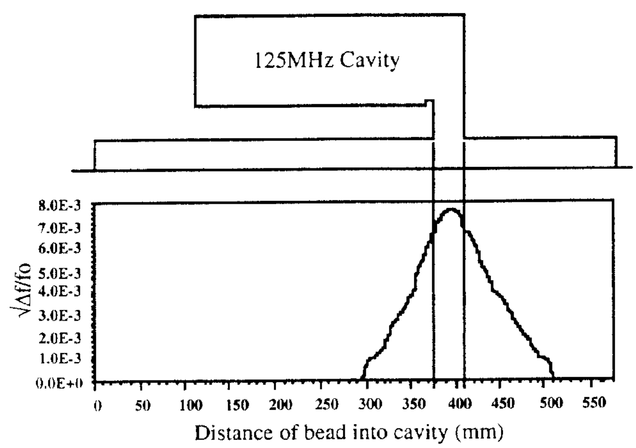

Figure 4. LabVIEW generated √Δf/fo vs distance graph.

The measurement system consists of four instruments, each controlled by a Macintosh computer via a GPIB interface using the data acquisition software LabVIEW and of course an RF cavity. The perturbing object (or bead) is suspended on a kevlar thread and is drawn through the centre of the cavity using a stepper motor controlled linear drive via a roller assembly each side of the cavity. A Network Analyser feeds the cavity with a narrow bandwidth (~20 kHz) signal, and a calibration measurement is made whereby all losses are eliminated due to lengths of cable etc. This calibration is then stored to a remote hard disk where the calibration coefficients may be called from at any time. Two sets of measurements are taken with the system, initially an unperturbed measurement is completed, during which a Q factor measurement is taken. The second is a perturbed measurement which uses the results of the unperturbed measurement to provide a solution to the integral part of equation (2).

LabVIEW is used to control every stage of the measurement process and plots a graph of √Δf/fo against distance as the bead travels the cavity's entire length (see figure 4), it is then integrated and a value of R_o / Q_o is output.

4. CONCLUSIONS

It is not the intention of this paper to suggest that LabVIEW is the ideal solution to all data acquisition problems. It is hoped that an insight has been given into the product and an objective assessment of its capabilities presented. There is little doubt that the product has shortcomings which may rule it out of certain applications. Amongst these are speed and cost. Although it claims to be as fast as compiled C, this is not our experience. In mathematically intensive routines, such as curve fitting, it appears to be significantly slower. Also, it is relatively expensive compared with conventional codes, not just in software terms but also in hardware terms. This is a memory hungry program (both RAM (≈6 Mb) and hard disk (≈25 Mb)) and requires a powerful PC to be used to its full potential.

However, there is no doubt that LabVIEW has many advantages which for many purposes outweigh the disadvantages mentioned above. For instance the learning and development times tend to be short. The LabVIEW techniques of programming can be picked up very quickly compared with conventional codes and programs can be rapidly developed especially using the VI libraries. Also there is greater flexibility, for example VIs can be adapted to meet changing requirements very quickly and by any programmer not just the author. Other advantages include the possibility of simultaneously running independent VIs on the same computer and the very professional appearance of the user front end.

5. REFERENCES

[1] National Instruments, Austin, Texas, USA.

[2] J.S. MacKay, "Electron beam profile, position systems and measurements on the Daresbury SRS", in Proceedings of the European Particle Accelerator Conference, Rome, Italy, June 1988, pp 43 - 45.

[3] R.J. Smith et al, "The Implementation of a Down Conversion Orbit Measurement Technique on the Daresbury SRS", these proceedings.

[4] E. Ginzton, Microwave Measurements, McGraw-Hill, 1957.

[5] P.A. McIntosh, "Perturbation measurements on RF cavities at Daresbury", these proceedings.