# Collection and Reduction of Digital Level Data at APS*

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*The Advanced Photon Source (APS) Survey and Alignment group at Argonne National Laboratory uses Leica digital levels for a majority of its precision leveling jobs. This poster describes the methodology and software tools developed for the NA3003 and DNA03 digital levels at APS. The implemented system, consisting of normalized nomenclature, special coding, Leica's firmware, and our processing software, enables us to collect measurements without laptops but without loosing any auxiliary data previously collectable only through an in-line laptop application.*

The primary and secondary vertical control networks at APS are maintained by traditional double-run differential leveling utilizing invar staffs and a DNA03 digital level from Leica. (We also used NA3003 in the past). Each leg in the network (Fig.1) is measured as a loop with each individual station also measured as a mini-loop (BFFB method). The turn points (TP) are fixed for the primary control network and there is an odd number of TPs between the benchmarks (BM) in each leg. Leica's digital levels provide firmware for the multiple measurements mode, BFFB method, enforcement of tolerances like distance balance, maximum distance, lowest staff height, permitted station difference, maximum difference for double observation (B1-B2, F1-F2), and loop closure [1].

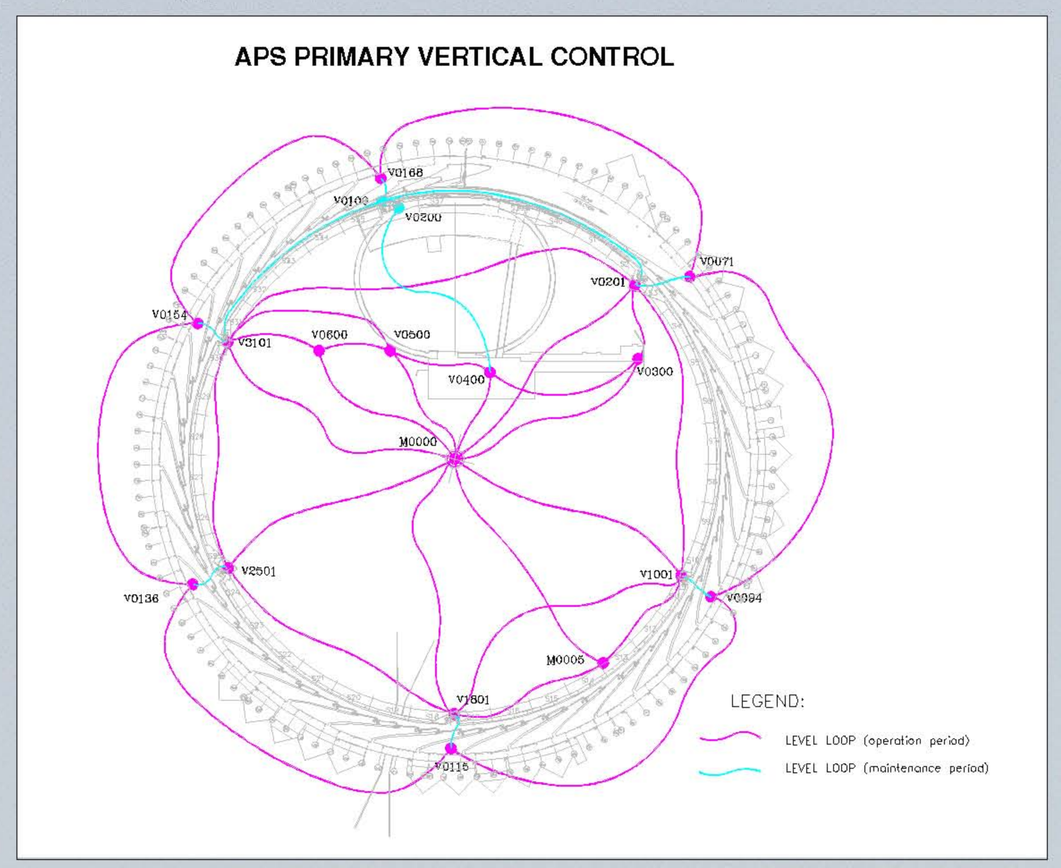


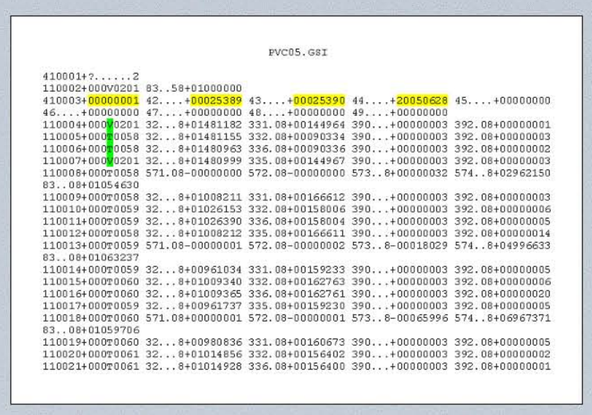

Figure 1.

In order to embed certain BM attributes in the data file, we have adopted a naming scheme for all the measured points. The standard ID format is 'ADDDD', where 'A' indicates an alphanumerical character, and 'D' is a digit (0–9). The first character 'A' is an indicator for the BM location as well as the BM type. Since all benchmarks starting with the same character are of the same physical construction, the point's offset constant (i.e. what the staff is resting on) can be determined from the ID of the point (Table 1). To store supplementary data with the measurements, we utilize the coding feature of Leica instruments. When measuring the level loop, a technician enters the *CODE 1* data block (staff-1 S/N, staff-2 S/N, and date) before starting the level loop (highlighted yellow in Fig. 2). As an administrative policy we always enter the staff with the lower S/N as staff-1 and start the new loop with staff-1.

| BM LOCATION / TYPE | BM ID starting character 'A' | BM Offset [m] | BM Offset ID (staff S/N postfix) |
|---|---|---|---|
| BOOSTER / FLOOR CUP | B | 0.044450 | TH |
| PRIMARY VERT. CONTROL / BRASS PLUG | V | 0.000000 | O |
| EX HALL COLUMN | C | 0.000000 | O |
| LINAC / FLOOR CUP | L | 0.044450 | TH |
| MAIN CONCRETE MONUMENTS | M | 0.047820 | A |
| SRING, EX HALL / FLOOR CUP | S | 0.044450 | TH |
| TURNING POINT | T | 0.000000 | O |
| LEUTL / FLOOR CUP | U | 0.044450 | TH |

Table 1. The shaded column added for backward compatibility.

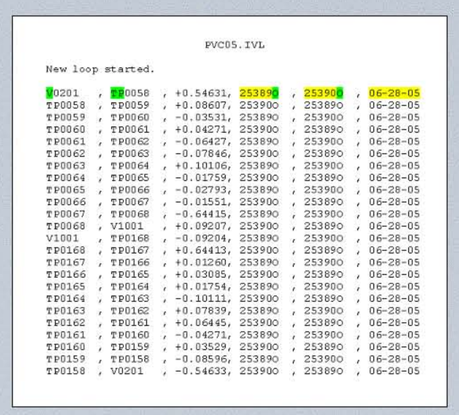
The leveling data is stored in Leica's *GSI-8* format [2] on a Compact Flash card and then uploaded to a PC (Fig. 2) for two-step data reduction. The *GSI* raw data file is first processed with the *DNA2GEO* program. *DNA2GEO* checks the internal integrity of the data, appends level rods with point-based offsets, and basically translates a *GSI* file into an *IVL* file format (Fig. 3). The *IVL* file is identical to the *INVLEVEL.IVL* file that would have been created if a laptop and the old SLAC's *DCAM* data collection programs had been used [3]. This step is not necessary, but we have used *DCAM* in the past and wanted to maintain an option of backward compatibility with the proven data processing software.



```
PVC05.GSI

410001+?......2
110002+000V0201 83..58+01000000
410003+00000001 42....+00025389 43....+00009306 44....+20050628 45....+00000000
46....+00000000 47....+00000000 48....+00000000 49....+00000000
110004+000V0201 32...8+01481182 331.08+00144964 390...+00000003 392.08+00000001
110005+000T0058 32...8+01481155 332.08+00090334 390...+00000003 392.08+00000003
110006+000T0058 32...8+01480963 336.08+00090336 390...+00000003 392.08+00000002
110007+000V0201 32...8+01480999 335.08+00144967 390...+00000003 392.08+00000003
110008+000T0058 571.08-00000000 572.08-00000000 573..8+00000032 574..8+02962150
83..08+01054630
110009+000T0058 32...8+01008211 331.08+00166612 390...+00000003 392.08+00000003
110010+000T0059 32...8+01026153 332.08+00158006 390...+00000003 392.08+00000006
110011+000T0059 32...8+01026390 336.08+00158004 390...+00000003 392.08+00000005
110012+000T0058 32...8+01008212 335.08+00166611 390...+00000003 392.08+00000014
110013+000T0059 571.08-00000001 572.08-00000002 573..8-00018029 574..8+04996633
83..08+01063237
110014+000T0059 32...8+00961034 331.08+00159233 390...+00000003 392.08+00000005
110015+000T0060 32...8+01009340 332.08+00162763 390...+00000003 392.08+00000006
110016+000T0060 32...8+01009365 336.08+00162761 390...+00000003 392.08+00000020
110017+000T0059 32...8+00961737 335.08+00159230 390...+00000003 392.08+00000005
110018+000T0060 571.08+00000001 572.08-00000001 573..8-00065996 574..8+06967371
83..08+01059706
110019+000T0060 32...8+00980836 331.08+00160673 390...+00000003 392.08+00000005
110020+000T0061 32...8+01014856 332.08+00156402 390...+00000003 392.08+00000002
110021+000T0061 32...8+01014928 336.08+00156400 390...+00000003 392.08+00000001
```

Figure 2.



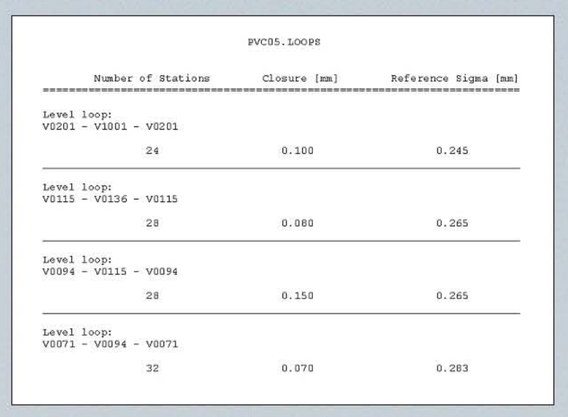
```
PVC05.IVL

New loop started.

V0201   , TP0058  , +0.54631, 253890 , 253900 , 06-28-05
TP0058  , TP0059  , +0.08607, 253900 , 253890 , 06-28-05
TP0059  , TP0060  , -0.03531, 253890 , 253900 , 06-28-05
TP0060  , TP0061  , +0.04271, 253900 , 253890 , 06-28-05
TP0061  , TP0062  , -0.06427, 253890 , 253900 , 06-28-05
TP0062  , TP0063  , -0.07846, 253900 , 253890 , 06-28-05
TP0063  , TP0064  , +0.10106, 253890 , 253900 , 06-28-05
TP0064  , TP0065  , -0.01759, 253900 , 253890 , 06-28-05
TP0065  , TP0066  , -0.02793, 253890 , 253900 , 06-28-05
TP0066  , TP0067  , -0.01551, 253900 , 253890 , 06-28-05
TP0067  , TP0068  , -0.64415, 253890 , 253900 , 06-28-05
TP0068  , V1001   , +0.09207, 253900 , 253890 , 06-28-05
V1001   , TP0168  , -0.09204, 253890 , 253900 , 06-28-05
TP0168  , TP0167  , +0.64413, 253900 , 253890 , 06-28-05
TP0167  , TP0166  , +0.01260, 253890 , 253900 , 06-28-05
TP0166  , TP0165  , +0.03085, 253900 , 253890 , 06-28-05
TP0165  , TP0164  , +0.01754, 253890 , 253900 , 06-28-05
TP0164  , TP0163  , -0.10111, 253900 , 253890 , 06-28-05
TP0163  , TP0162  , +0.07839, 253890 , 253900 , 06-28-05
TP0162  , TP0161  , +0.06445, 253900 , 253890 , 06-28-05
TP0161  , TP0160  , -0.04271, 253890 , 253900 , 06-28-05
TP0160  , TP0159  , +0.03529, 253900 , 253890 , 06-28-05
TP0159  , TP0158  , -0.08596, 253890 , 253900 , 06-28-05
TP0158  , V0201   , -0.54633, 253900 , 253890 , 06-28-05
```

Figure 3.

The preprocessed leveling data from the *IVL*-type file obtained from step one is further reduced with the *LEVRED2* tool. Program *LEVRED2* requires access to an auxiliary external file *ROD.DAT* containing leveling staffs calibration data. *LEVRED2* creates two files – a file with extension *LEGS* and a file with extension *LOOPS*. The *LOOPS* file (Fig. 4) contains a summary of the level loops: it lists the BMs in the loop, number of stations, loop closure, and reference sigma. A reference sigma is a standard deviation of the vertical difference of the loop based on 50 microns per station propagated over a number of stations in the loop. Loops with closures exceeding this value are flagged for closer inspection. The *LEGS* file (Fig. 5) lists the starting and ending BM for each leg, the vertical difference between these BMs corrected for monument offset, the leveling staffs' calibration offset, a standard deviation for the leg, and the number of stations in the leg. The *LEGS* file is in a format compatible with the input for a least-squares adjustment program like *T1RF* or *T1RA* [3], which we continue to use for vertical control network adjustment.

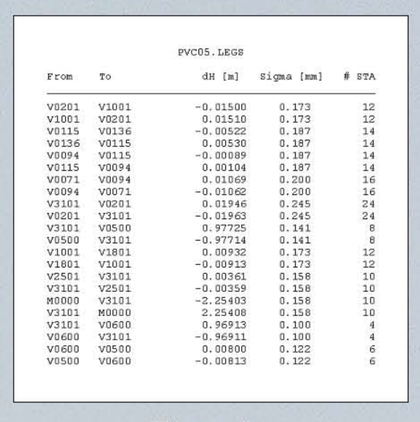


```
PVC05.LOOPS

        Number of Stations        Closure [mm]        Reference Sigma [mm]
==========================================================================

Level loop:
V0201 - V1001 - V0201
                24                0.100                0.245
--------------------------------------------------------------------------
Level loop:
V0115 - V0136 - V0115
                28                0.080                0.265
--------------------------------------------------------------------------
Level loop:
V0094 - V0115 - V0094
                28                0.150                0.265
--------------------------------------------------------------------------
Level loop:
V0071 - V0094 - V0071
                32                0.070                0.283
```

Figure 4.

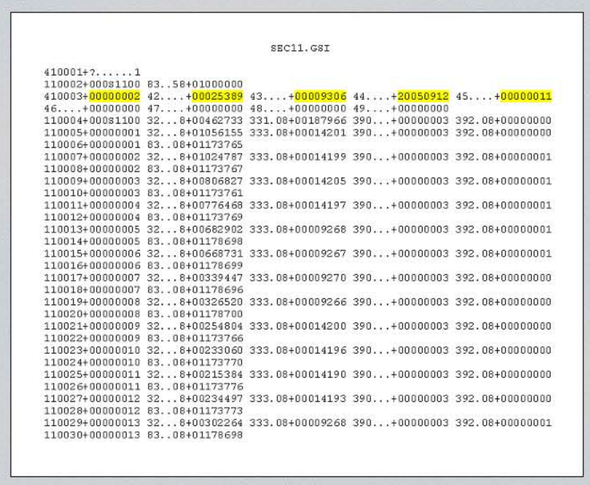


```
PVC05.LEGS

From    To              dH [m]    Sigma [mm]   # STA
-------------------------------------------------------
V0201   V1001         -0.01500      0.173        12
V1001   V0201          0.01510      0.173        12
V0115   V0136         -0.00522      0.187        14
V0136   V0115          0.00530      0.187        14
V0094   V0115         -0.00089      0.187        14
V0115   V0094          0.00104      0.187        14
V0071   V0094          0.01069      0.200        16
V0094   V0071         -0.01062      0.200        16
V3101   V0201          0.01946      0.245        24
V0201   V3101         -0.01963      0.245        24
V3101   V0500          0.97725      0.141         8
V0500   V3101         -0.97714      0.141         8
V1001   V1801          0.00932      0.173        12
V1801   V1001         -0.00913      0.173        12
V2501   V3101          0.00361      0.158        10
V3101   V2501         -0.00359      0.158        10
M0000   V3101         -2.25403      0.158        10
V3101   M0000          2.25408      0.158        10
V3101   V0600          0.96913      0.100         4
V0600   V3101         -0.96911      0.100         4
V0600   V0500          0.00800      0.122         6
V0500   V0600         -0.00813      0.122         6
```

Figure 5.

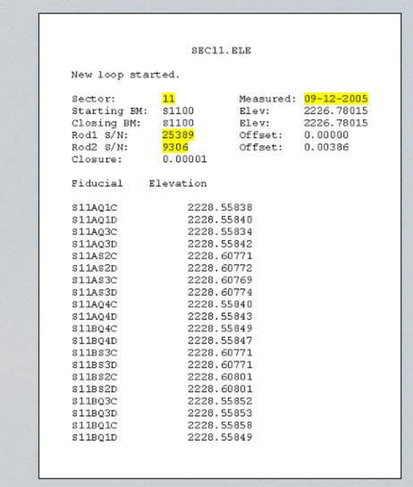
In addition to the vertical control network, we also utilize digital levels for magnet mapping in APS subsystems. Appropriate methodology, codes, and processing tools were developed to simplify these repeatable tasks. For example, in the APS storage ring, twenty sequential points per sector are measured in forty repeating sectors. This job is accomplished by measuring one station setup with twenty side shots in each sector (Fig. 6). The *GETSECTOR* tool then translates the *GSI* measurement file, retrieves the BM elevation and rod calibration data, checks the loop closure, and generates actual fiducial names and their elevations (Fig. 7). The influence of collimation error on side shots of unequal distances is kept within reasonable limits by the calibration procedure performed daily before the magnet mapping.



```
SEC11.GSI

410001+?......1
110002+00081100 83..58+01000000
410003+00000002 42....+00025389 43....+00009306 44....+00000011
46....+00000000 47....+00000000 48....+00000000 49....+00000000
110004+00081100 32...8+00462733 331.08+00187966 390...+00000003 392.08+00000000
110005+00000001 32...8+01056155 333.08+00014201 390...+00000003 392.08+00000000
110006+00000001 83..08+01173765
110007+00000002 32...8+01024787 333.08+00014199 390...+00000003 392.08+00000001
110008+00000002 83..08+01173767
110009+00000003 32...8+00806827 333.08+00014205 390...+00000003 392.08+00000001
110010+00000003 83..08+01173761
110011+00000004 32...8+00776468 333.08+00014197 390...+00000003 392.08+00000001
110012+00000004 83..08+01173769
110013+00000005 32...8+00682902 333.08+00009268 390...+00000003 392.08+00000001
110014+00000005 83..08+01178698
110015+00000006 32...8+00668731 333.08+00009267 390...+00000003 392.08+00000001
110016+00000006 83..08+01178699
110017+00000007 32...8+00339447 333.08+00009270 390...+00000003 392.08+00000000
110018+00000007 83..08+01178696
110019+00000008 32...8+00326520 333.08+00009266 390...+00000003 392.08+00000000
110020+00000008 83..08+01178700
110021+00000009 32...8+00254804 333.08+00014200 390...+00000003 392.08+00000000
110022+00000009 83..08+01173766
110023+00000010 32...8+00233060 333.08+00014196 390...+00000003 392.08+00000000
110024+00000010 83..08+01173770
110025+00000011 32...8+00215384 333.08+00014190 390...+00000003 392.08+00000000
110026+00000011 83..08+01173776
110027+00000012 32...8+00234497 333.08+00014193 390...+00000003 392.08+00000000
110028+00000012 83..08+01173773
110029+00000013 32...8+00302264 333.08+00009268 390...+00000003 392.08+00000001
110030+00000013 83..08+01178698
```

Figure 6.



```
SEC11.ELE

New loop started.

Sector:          11          Measured: 09-12-2005
Starting BM:     S1100       Elev:     2226.78015
Closing BM:      S1100       Elev:     2226.78015
Rod1 S/N:        25389       Offset:   0.00000
Rod2 S/N:        9306        Offset:   0.00386
Closure:         0.00001

Fiducial     Elevation

S11AQ1C          2228.55838
S11AQ1D          2228.55840
S11AQ3C          2228.55834
S11AQ3D          2228.55842
S11AS2C          2228.60771
S11AS2D          2228.60772
S11AS3C          2228.60769
S11AS3D          2228.60774
S11AQ4C          2228.55840
S11AQ4D          2228.55843
S11BQ4C          2228.55849
S11BQ4D          2228.55847
S11BS3C          2228.60771
S11BS3D          2228.60771
S11BS2C          2228.60801
S11BS2D          2228.60801
S11BQ3C          2228.55852
S11BQ3D          2228.55853
S11BQ1C          2228.55858
S11BQ1D          2228.55849
```

Figure 7.

The APS Survey and Alignment group wanted to free themselves of laptop data collectors when performing differential leveling. We have developed and implemented a simple solution that we have been using now for several years with positive feedback from our technicians. This could not have been accomplished without great support from APS/SA group leader Horst Friedsam and APS/SA technicians Kris Mietsner and Keith Knight who methodically tested the procedure during the development stage.

## REFERENCES

[1] DNA03/DNA10 User Manual, 726203-1.1en, Leica Geosystems AG, Heerbrugg Switzerland, 2002.

[2] Wild Instruments On Line, G2-366-Oen – VI.97, Leica AG, Heerbrugg Switzerland, 1998.

[3] GEONET, *Stanford Linear Accelerator Center Survey and Alignment Workshop on Data Processing Using Geonet for Accelerator Alignment*, SLAC-PUB-395, February 1992.

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