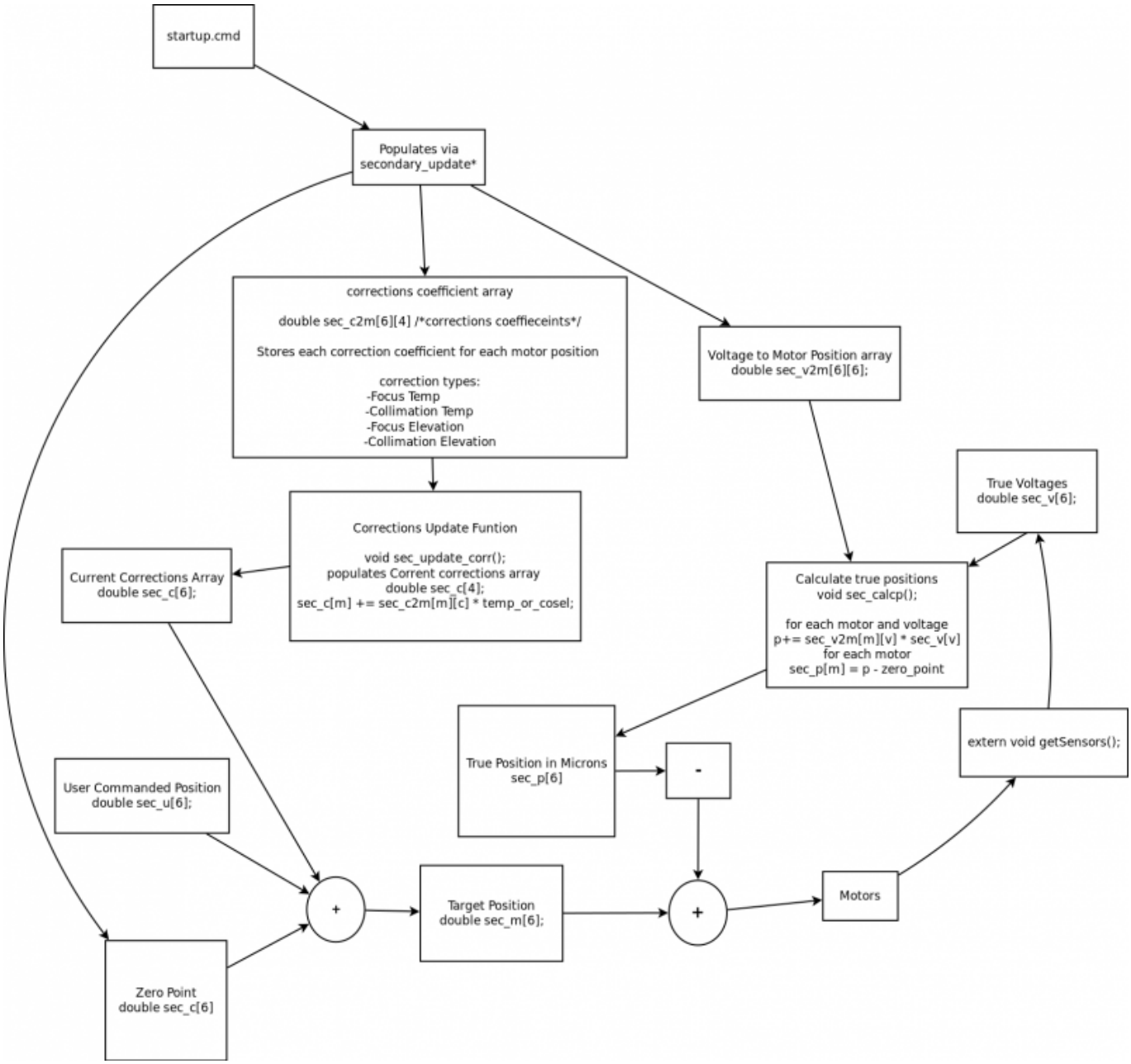
VATT Pseudo Hexapod (Legacy)

The VATT secondary is focused and collimated with a Pseudo Hexapod. Motion between the axes are coupled but as little as possible and we get uncoupled positions with some linear algebra and iterations. The pseudo hexapod is to be retired for a PI hexapod which will be installed summer 2017

Software

The VATT secondary is controlled using a c program that runs on vatttel. You can find the source in our mogit repository. The most important source file is secmove.c, which controls the autofocus, autocollimation and closed loop motion. A block diagram and the source code for this module are below.



```
/* VATT secondary move routine
 * The six user motions are all cross coupled
 * into the six motors on the VATT secondary.
 * Hence, all the matrix math.
 * This will be a replacement for winsec.c
 */
#define abs(a)            ((a) < 0 ? -(a) : (a))

extern void    sprintf();
extern void    printf();
extern int    sec_checkVoltsOK();
extern void    movev();
extern void    vme8_kill();

double sec_dv = 0.03;        /* maximum allowable voltage difference */
double sec_dvmax = 0.2;    /* maximum before kill */
double sec_min_temp = -40.0;    /* minimum sane temperature */
double sec_max_temp =  50.0;    /* maximum sane temperature */
double sec_min_cosel = 0.0;    /* minimum sane cosine(elevation) */
double sec_max_cosel = 1.0;    /* maximum sane cosine(elevation) */
double sec_lastgood_temp;    /* last sane temperature */
double sec_lastgood_cosel;    /* last sane cosine(elevation) */
int    sec_max_mloops = 5;    /* maximum motor loops */

#define V       6       /* number of motors/sensors */
#define M       6       /* number of user motions */
#define TIPX    0       /* arcseconds */
#define TIPY    1
#define TIPZ    2
#define DECENX  3       /* microns */
#define DECENY  4
#define FOCUS   5

double sec_threshold[M] = {2.5, 2.5, 2.5, 4.5, 4.5, 1.0};
char   sec_errormessage[100];        /* error message */
double  sec_u0[M];      /* previous user values */
double  sec_u[M];       /* user values */
double  sec_c[M];       /* corrections */
double  sec_m[M];       /* target motions */
double  sec_t[V];       /* target voltages */
double  sec_v[V];       /* true voltages */
double  sec_p[M];       /* true positions */

/* The immediately above positions are derived from the lvdt readings
 * and multiplied by v2m, then the zero offset is removed.
 */

#define C       4       /* number of corrections */
#define FTC     0
#define FLC     1
```

```
#define CTC     2
#define CLC     3


/* the original Steve West matrix
 */
double sec_m2v_sw[V][M] = {
{0.0029680,   0.0051070, -0.0001555, -0.0000931, -0.0001510, -0.0069780},
{0.0016000,  -0.0007957, -0.0033810, -0.0033320, -0.0058000, -0.0003111},
{0.0029300,  -0.0050660, -0.0000175, -0.0000407,  0.0000389, -0.0069420},
{-0.001475,  -0.0010590, -0.0032270, -0.0031640,  0.0057680, -0.0004334},
{-0.005346,  -0.0000617,  0.0000176,  0.0000674,  0.0001066, -0.0063050},
{-0.0001785,  0.0017840, -0.0034270,  0.0065690,  0.0000873, -0.0002048}
};

/* All new values per cromwell 10/6/97
 * Most of these are now updated in startup.cmd
 */

double  sec_z[M] = {0.0, 0.0, 0.0, 0.0, 0.0, 0.0};
double  sec_z0[M] = {0.0, 0.0, 0.0, 0.0, 0.0, 0.0};

double sec_m2v[V][M] = {
{0.0029680,   0.0051070, -0.0001555, -0.0000931, -0.0001510, -0.0069780},
{0.0016000,  -0.0007957, -0.0033810, -0.0033320, -0.0058000, -0.0003111},
{0.0029300,  -0.0050660, -0.0000175, -0.0000407,  0.0000389, -0.0069420},
{-0.001475,  -0.0010590, -0.0032270, -0.0031640,  0.0057680, -0.0004334},
{-0.005346,  -0.0000617,  0.0000176,  0.0000674,  0.0001066, -0.0063050},
{-0.0001785,  0.0017840, -0.0034270,  0.0065690,  0.0000873, -0.0002048}
};

double sec_v2m[M][V] = {
{  55.4830132,   -3.6541212,   58.2489128,   -0.3046370, -125.3519897,
0.4331740, },
{  98.1537399,   -3.2015131,  -98.2364426,    0.0305685,   -0.2867458,
-0.8237946, },
{   3.4616468, -100.5291290,    5.1929183,  -99.6347046,    5.4746866,
-98.9561157, },
{ -25.0618916,  -50.5131302,   29.3149300,  -53.1427689,   -1.6702332,
100.8553619, },
{  16.7931938,  -85.4085464,   12.2465286,   88.4728470,  -33.9353485,
-0.0462751, },
{ -47.9787979,    0.8650305,  -47.8929024,    0.9076155,  -52.8920479,
0.4418988, },
};

double sec_c2m[M][C] = {
{   0.0,    0.0,   0.0,   0.0, },
{   0.0,    0.0,   0.0,   0.0, },
{   0.0,    0.0,   0.0,   0.0, },
{   0.0,    0.0,   0.0,   0.0, },
```

```
{   0.0,    0.0,   0.0,   0.0, },
{   0.0,    0.0,   0.0,   0.0, },
};

void
sec_update_Z (m0, m1, m2, m3, m4, m5)
double m0;
double m1;
double m2;
double m3;
double m4;
double m5;
{
    int    m;
    double mm[M];

    mm[0] = m0;
    mm[1] = m1;
    mm[2] = m2;
    mm[3] = m3;
    mm[4] = m4;
    mm[5] = m5;

    for (m = 0; m < M; m++) {
        sec_z[m] = mm[m];
        sec_z0[m] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_nelsonCT (m0, m1, m2, m3, m4, m5)
double m0;
double m1;
double m2;
double m3;
double m4;
double m5;
{
    int    m;
    double mm[M];

    mm[0] = m0;
    mm[1] = m1;
    mm[2] = m2;
    mm[3] = m3;
    mm[4] = m4;
    mm[5] = m5;

    for (m = 0; m < M; m++) {
```

```
        sec_c2m[m][CTC] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_nelsonCL (m0, m1, m2, m3, m4, m5)
double m0;
double m1;
double m2;
double m3;
double m4;
double m5;
{
    int    m;
    double mm[M];

    mm[0] = m0;
    mm[1] = m1;
    mm[2] = m2;
    mm[3] = m3;
    mm[4] = m4;
    mm[5] = m5;

    for (m = 0; m < M; m++) {
        sec_c2m[m][CLC] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_nelsonFT (m5)
double m5;
{
    sec_c2m[FOCUS][FTC] = m5;
}

void
sec_update_nelsonFL (m5)
double m5;
{
    sec_c2m[FOCUS][FLC] = m5;
}

void
sec_engzero ()
{
    int    m;

    for (m = 0; m < M; m++) {
        sec_u[m] -= sec_z0[m]-sec_z[m];
```

```
        sec_z[m] += sec_z0[m]-sec_z[m];
    }
}

void
sec_userzero ()
{
    int    m;

    for (m = 0; m < M; m++) {
        sec_z[m] += sec_u[m];
        sec_u[m] = 0.0;
    }
}

void
sec_logger (orig, mess)
char   *orig;
char   *mess;
{
    void    vxcall();

    vxcall ("_logger_it", orig, mess, 0,0,0,0,0,0,0,0);
}

int
sec_telslewing()
{
    int    telslewing = 0;
    void    vxcall();

    vxcall ("_telx_sec_telslewing", &telslewing, 0,0,0,0,0,0,0,0,0);
    return (telslewing);
}


int    sec_working;
double sec_azimuth;
double sec_derotator;
double sec_elevation;        /* current altitude in radians */
double sec_temperature;    /* current temperature in degrees C */
static  int     sec_autofocus;
static  int     sec_autocoll;

void
sec_update_tl ()        /* update temperature and elevation */
{
    void    vxcall();

    vxcall ("_telx_sec_temperature", &sec_temperature, 0,0,0,0,0,0,0,0,0);
```

```
    vxcall ("_telx_sec_elevation"   , &sec_elevation   , 0,0,0,0,0,0,0,0,0);
    vxcall ("_telx_sec_azimuth"   , &sec_azimuth   , 0,0,0,0,0,0,0,0,0);
    vxcall ("_telx_sec_derotator"   , &sec_derotator   , 0,0,0,0,0,0,0,0,0);
}

void
sec_autoreset ()
{
}

void
sec_autofocus_set (status)
int     status;
{
        sec_autofocus = status;
}

int
sec_autofocus_get ()
{
        return (sec_autofocus);
}

void
sec_autocoll_set (status)
int     status;
{
        sec_autocoll = status;
}

int
sec_autocoll_get ()
{
        return (sec_autocoll);
}

void
sec_update_corr ()
{
        int     m, c;
        double  sc;
        double  temp, cosel;
        double d[C];
        double cos();

        sec_update_tl ();
    temp = sec_temperature;
    cosel = cos(sec_elevation);

    /* sanity checks
     */
```

```
    if (sec_min_temp < temp && temp < sec_max_temp) {
        sec_lastgood_temp = temp;
    } else {
        temp = sec_lastgood_temp;
    }
    if (sec_min_cosel < cosel && cosel < sec_max_cosel) {
        sec_lastgood_cosel = cosel;
    } else {
        cosel = sec_lastgood_cosel;
    }

        d[FTC] = sec_autofocus ? temp : 0.0;
        d[FLC] = sec_autofocus ? cosel : 0.0;
        d[CTC] = sec_autocoll ? temp : 0.0;
        d[CLC] = sec_autocoll ? cosel : 0.0;

        for (m = 0; m < M; m++) {
            sc = 0.0;
            for (c = 0; c < C; c++) {
                sc += sec_c2m[m][c] * d[c];
            }
            sec_c[m] = sc;
        }
}

void
sec_calct ()    /* calculate targets */
{
        int     m, v;
        double  t;

        for (v = 0; v < V; v++) {
            t = 0.0;
            for (m = 0; m < M; m++) {
                sec_m[m] = sec_u[m]+sec_c[m]+sec_z[m];
                t += sec_m2v[v][m] * sec_m[m];
            }
            sec_t[v] = t;
        }
}

void
sec_calcp ()    /* calculate true positions */
{
        int     m, v;
        double  p;

    for (m = 0; m < M; m++) {
            p = 0.0;
        for (v = 0; v < V; v++) {
```

```
                p += sec_v2m[m][v] * sec_v[v];
            }
            sec_p[m] = p - sec_z[m];
        }
}

int
sec_checkMove()
{
    int    v;
    int    mstatus = 0;
    int    rstatus = 0;
    double    residual;
    char    errormessage[100];
    int    strlen();

    errormessage[0] = 0;
    for (v = 0; v < V; v++) {
        residual = sec_t[v]-sec_v[v];
        sprintf (errormessage+strlen(errormessage), " %.4f", residual);
        if (abs(residual) > sec_dv)
        mstatus = 1;
        if (abs(residual) > sec_dvmax)
        rstatus = 1;
    }
    if (mstatus)
        sprintf (sec_errormessage, "residuals =%s", errormessage);
    return (rstatus);
}

void
sec_voltsNotOK ()
{
    int    v;
    char    errormessage[100];
    int    strlen();

    errormessage[0] = 0;
    for (v = 0; v < V; v++) {
        sprintf (errormessage+strlen(errormessage), " %.4f", sec_t[v]);
    }
    sprintf (sec_errormessage, "bad target =%s", errormessage);
}

void
sec_sprintf (c, array)
char   *c;
double array[];
{
    int    m;
    int    strlen();
```

```
    *c = 0;
    for (m = 0; m < M; m++) {
        sprintf (c+strlen(c), " %12.6f", array[m]);
    }
}

void
sec_sprintfu (c, array, array0)
char   *c;
double array[];
double array0[];
{
    int    m;
    int    strlen();

    *c = 0;
    for (m = 0; m < M; m++) {
        sprintf (c+strlen(c), " %d", array[m] != array0[m]);
        array0[m] = array[m];
    }
}

void
sec_log_servc ()
{
    char    c[100];
    double    readmotorcurrent ();

    sprintf (c, "%12.6f %12.6f %12.6f", readmotorcurrent (4),
      readmotorcurrent (2), readmotorcurrent (3));
    sec_logger ("serv_c", c);
}

void
sec_log ()
{
    char    c[100];
    int    strlen();
        double cos();

    sprintf (c, "%12.6f %12.6f %12.6f %12.6f %12.6f",
      sec_elevation*57.29577951,
      cos(sec_elevation),
      sec_temperature,
      sec_azimuth*57.29577951,
      sec_derotator*57.2957795);
    sec_logger ("sec_el", c);
    sec_sprintf (c, sec_u);
    sec_sprintfu (c+strlen(c), sec_u, sec_u0);
```

```
    sec_logger ("sec_u", c);
    sec_sprintf (c, sec_c);
    sec_logger ("sec_c", c);
    sec_sprintf (c, sec_z);
    sec_logger ("sec_z", c);
    sec_sprintf (c, sec_m);
    sec_logger ("sec_m", c);
    sec_sprintf (c, sec_t);
    sec_logger ("sec_t", c);
    sec_sprintf (c, sec_v);
    sec_logger ("sec_v", c);
    sec_sprintf (c, sec_p);
    sec_logger ("sec_p", c);
    sec_log_servc ();
}

void
sec_loop_init ()
{
    void    getSensors();
        int     m;

    getSensors ();
    sec_calcp ();
    for (m = 0; m < M; m++) {
            sec_u[m] = sec_p[m];
            sec_u0[m] = sec_u[m];
    }
    sec_log ();
}

void
sec_loop (timedout)
int    timedout;    /* !0 if triggered by timer */
{
    int    n;
    int    m;
    int    big;
    void    strcpy();
    void    getSensors();

    if (!timedout || ((sec_autofocus||sec_autocoll) && !sec_telslewing())) {
        sec_working = 1;
        sec_update_corr ();
        sec_calct ();
        if (sec_checkVoltsOK (sec_t)) {
        getSensors ();
        sec_calcp ();
        for (n = 0; n < sec_max_mloops; n++) {
            big = 0;
            for (m = 0; m < M; m++) {
```

```
            big |= abs(sec_m[m]-sec_z[m]-sec_p[m])
              > sec_threshold[m];
            }
            if (!big)
            break;
            strcpy (sec_errormessage, "moving");
            movev (sec_t);
            strcpy (sec_errormessage, "");
            getSensors ();
            sec_calcp ();
        }
        if (sec_checkMove ()) {
            vme8_kill ();
        }
        } else {
        sec_voltsNotOK ();
        sec_calcp ();
        }
        sec_log ();
        sec_working = 0;
    }
}

void
sec_printf (id, array)
char   *id;
double array[];
{
    int    m;

    printf ("%s:", id);
    for (m = 0; m < M; m++) {
        printf (" %12.6f", array[m]);
    }
    printf ("\n");
}

void
sec_printd (id, array)
char   *id;
int    array[];
{
    int    m;

    printf ("%s:", id);
    for (m = 0; m < M; m++) {
        printf (" %12d", array[m]);
    }
    printf ("\n");
}
```

```
extern int    sec_s[];

void
sec_print ()
{
    printf ("%s\n", sec_errormessage);
    sec_printf ("z", sec_z);
    sec_printf ("u", sec_u);
    sec_printf ("c", sec_c);
    sec_printf ("m", sec_m);
    sec_printf ("t", sec_t);
    sec_printd ("s", sec_s);
    sec_printf ("v", sec_v);
    sec_printf ("p", sec_p);
    sec_errormessage[0] = 0;
}

void
telx_log_servc ()
{
    sec_log_servc ();
}

void
telx_lvdts ()
{
    int    v;
    char    errormessage[100];
    int    strlen();

    errormessage[0] = 0;
    for (v = 0; v < V; v++) {
        sprintf (errormessage+strlen(errormessage), " %.4f", sec_v[v]);
    }
    sprintf (sec_errormessage, "lvdts =%s", errormessage);
}

void
telx_rlvdts ()
{
    void    getSensors();

    getSensors ();
    telx_lvdts ();
    sec_calcp ();
    sec_log ();
}

void
plvdts ()
```

```
{
    void    getSensors();
    int    v;

    getSensors ();
    telx_lvdts ();
    sec_calcp ();

    printf ("lvdts =");
    for (v = 0; v < V; v++) {
        printf (" %.4f", sec_v[v]);
    }
    printf ("\n");
}

void
pmcurr ()
{
    double    readmotorcurrent ();

    printf ("%12.6f %12.6f %12.6f\n", readmotorcurrent (4),
      readmotorcurrent (2), readmotorcurrent (3));
}

int    telvatt_telfocustimeout = 70;
int    telvatt_telfocuscmdlevel;

void
telvatt_telfocus (c)
char   *c;
{
    void    sleep();
    void    secondary_trigger();
    int    sscanf();
    double    focus;
    int    timeout = telvatt_telfocustimeout;

    if ((telvatt_telfocuscmdlevel > 0) && (sscanf(c,"%lf",&focus) == 1)) {
        sec_u[FOCUS] = focus;
        sec_working = 1;
        secondary_trigger();
        while (sec_working && timeout--)
        sleep (1);
    }
    sprintf (c, "%.2f", sec_u[FOCUS]);
}
#ifdef OUTOFDATE
/* This is an arbitrary zero point for the user motions.
 *
 * It was derived using Tom T.'s goodplace lvdt values
```

```
 * and multiplying by the v2m matrix.
 * { 4.348, -6.021, 5.151, -5.925, 3.126, -5.148 }
double  sec_z[M] = {97.0968554,-46.2452714,1763.9614446,
                    136.6180699,20.2980418,-633.5096204};
 * new values 3/25/97 via cromwell->nelson->harvey
double  sec_z[M] = {-103.1331446,38.2247286,1763.9614446,
                    150.2880699,-0.5719582,-658.7596204};
double  sec_z0[M] = {-103.1331446,38.2247286,1763.9614446,
                    150.2880699,-0.5719582,-658.7596204};
 * new values 5/30/97
 */
double  sec_z[M] = {-273.5316558,168.0022732,1962.0991461,
                    26.3139608,-168.5847471,-427.0699187};
double  sec_z0[M] = {-273.5316558,168.0022732,1962.0991461,
                    26.3139608,-168.5847471,-427.0699187};

/* Steve West's original matrix
{0.0029680,   0.0051070, -0.0001555, -0.0000931, -0.0001510, -0.0069780},
{0.0016000,  -0.0007957, -0.0033810, -0.0033320, -0.0058000, -0.0003111},
{0.0029300,  -0.0050660, -0.0000175, -0.0000407,  0.0000389, -0.0069420},
{-0.001475,  -0.0010590, -0.0032270, -0.0031640,  0.0057680, -0.0004334},
{-0.005346,  -0.0000617,  0.0000176,  0.0000674,  0.0001066, -0.0063050},
{-0.0001785,  0.0017840, -0.0034270,  0.0065690,  0.0000873, -0.0002048}
 */

/* The following matrix of user motions (across) to lvdt voltages (down)
 * already has the following correction applied.
 */

/* There is correction in dtx and dty when applying focus. There are
 * 2 reasons: the positioner is mounted slightly tilted wrt to
 * the primary axis, and the primary comes up on its supports
 * slightly differently each time causing a small but variable
 * tilt term.  For now, this correction approximates the constant
 * term for mounting misalignment and the tilt for which the primary
supports
 * usually produce.
 * dtxSlope = -0.1166667;
 * dtySlope = 0.0166667;
 */

double sec_m2v[V][M] = {
{ 0.0029680,  0.0051070, -0.0001555, -0.0000931, -0.0001510, -0.0072391, },
{ 0.0016000, -0.0007957, -0.0033810, -0.0033320, -0.0058000, -0.0005110, },
{ 0.0029300, -0.0050660, -0.0000175, -0.0000407,  0.0000389, -0.0073683, },
{-0.0014750, -0.0010590, -0.0032270, -0.0031640,  0.0057680, -0.0002790, },
{-0.0053460, -0.0000617,  0.0000176,  0.0000674,  0.0001066, -0.0056823, },
{-0.0001785,  0.0017840, -0.0034270,  0.0065690,  0.0000873, -0.0001542, },
};

/* The following matrix of lvdt voltages (across) to user motions (down)
```

```
 * is the inversion of the above.
 */

double sec_v2m[M][V] = {
{ 49.8854752,  -3.5532007, 52.6613884, -0.1987483,-131.5227203,  0.4847288,
},
{ 98.9533844,  -3.2159302,-97.4382248,  0.0154418,   0.5947783, -0.8311595,
},
{  3.4616475,-100.5291367,  5.1929212,-99.6347046,   5.4746842,-98.9561081,
},
{-25.0618954, -50.5131378, 29.3149300,-53.1427727,  -1.6702307,100.8553619,
},
{ 16.7931862, -85.4085312, 12.2465229, 88.4728546, -33.9353409, -0.0462707,
},
{-47.9788094,   0.8650309,-47.8929062,  0.9076155, -52.8920441,  0.4418987,
},
};

/* The following matrix of (T,L) corrections (across)
 * {focus_delta_temperature,       focus_delta_sin_elevation,
 *  collimation_delta_temperature, collimation_delta_sin_elevation}
 * to user motion corrections (down)
 *
 * These were derived from Cromwell's original (June 10, 1996) coefficients
 * for ELCdv and TCdv by multiplying by v2m.
 * 0.2230000    0.0914000   -0.1024000   -0.0426000    0.0031000
0.1702000
 * 0.2148000    0.5129000    0.0363000    0.1717000   -0.0712000
0.4409000
 */

double sec_c2m[M][C] = {
{  0.0,    0.0,  20.3485814,  5.0904193, },
{  0.0,    0.0,  15.6625737, 31.6100656, },
{  0.0,    0.0,-111.7561536,-21.5290905, },
{  0.0,    0.0,   5.2340839,  6.2167347, },
{  0.0,    0.0, -22.1677258, -9.1975216, },
{ 15.0, -120.0,  -7.4841021, -5.8433957, },
};

/* values as of 10/6/97
 */

double sec_c2m[M][C] = {
{  0.0,    0.0,  21.2217299,  5.7721492, },
{  0.0,    0.0,  15.5378383, 31.5126765, },
{  0.0,    0.0,-111.7561535,-21.5290909, },
{  0.0,    0.0,   5.2340894,  6.2167361, },
{  0.0,    0.0, -22.1677345, -9.1975223, },
{ 15.0, -120.0,  -7.4840994, -5.8433935, },
```

```
};


void
sec_update_cromwellB (v0, v1, v2, v3, v4, v5)
double v0;
double v1;
double v2;
double v3;
double v4;
double v5;
{
    int    v, m;
    double vv[V];
    double mm[M];

    vv[0] = v0;
    vv[1] = v1;
    vv[2] = v2;
    vv[3] = v3;
    vv[4] = v4;
    vv[5] = v5;

    for (m = 0; m < M; m++) {
        mm[m] = 0.0;
        for (v = 0; v < V; v++) {
        mm[m] += sec_v2m[m][v]*vv[v];
        }
        sec_c2m[m][CLC] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_cromwellB0 ()
{
    sec_update_cromwellB (0.2230000,0.0914000,-0.1024000,
      -0.0426000,0.0031000,0.1702000);
}

void
sec_update_cromwellC (v0, v1, v2, v3, v4, v5)
double v0;
double v1;
double v2;
double v3;
double v4;
double v5;
{
    int    v, m;
    double vv[V];
```

```
    double mm[M];

    vv[0] = v0;
    vv[1] = v1;
    vv[2] = v2;
    vv[3] = v3;
    vv[4] = v4;
    vv[5] = v5;

    for (m = 0; m < M; m++) {
        mm[m] = 0.0;
        for (v = 0; v < V; v++) {
        mm[m] += sec_v2m[m][v]*vv[v];
        }
        sec_c2m[m][CTC] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_cromwellC0 ()
{
    sec_update_cromwellC (0.2148000,0.5129000,0.0363000,
      0.1717000,-0.0712000,0.44090000);
}

void
sec_update_cromwellZ (v0, v1, v2, v3, v4, v5)
double v0;
double v1;
double v2;
double v3;
double v4;
double v5;
{
    int    v, m;
    double vv[V];
    double mm[M];

    vv[0] = v0;
    vv[1] = v1;
    vv[2] = v2;
    vv[3] = v3;
    vv[4] = v4;
    vv[5] = v5;

    for (m = 0; m < M; m++) {
        mm[m] = 0.0;
        for (v = 0; v < V; v++) {
        mm[m] += sec_v2m[m][v]*vv[v];
```

```
        }
        sec_z[m] = mm[m];
        sec_z0[m] = mm[m];
        printf ("%.7f\n", mm[m]);
    }
}

void
sec_update_cromwellZ0 ()
{
    sec_update_cromwellZ (0.0,0.0,0.0,
      0.0,0.0,0.0);
}

/* auto variables */
/* focus versus temperature */
double  sec_ft0;  /* starting point */
double  sec_ft1;  /* last measurement */
double  sec_ft2;  /* measurement at last adjustment */
double  sec_fdt0; /* accumulated delta */
double  sec_fdt;  /* delta */
/* focus versus elevation */
double  sec_fl0;
double  sec_fl1;
double  sec_fl2;
double  sec_fdsl0;
double  sec_fdsl;
/* collimation versus temperature */
double  sec_ct0;
double  sec_ct1;
double  sec_ct2;
double  sec_cdt0;
double  sec_cdt;
/* collimation versus elevation */
double  sec_cl0;
double  sec_cl1;
double  sec_cl2;
double  sec_cdsl0;
double  sec_cdsl;
#endif
```

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Last update: **2018/03/19 20:33**