VERTEX ANTENNENTECHNIK GmbH
Ein Unternehmen der General Dynamics Gruppe

AMiBA TELESCOPE

HEXAPOD MOUNT

Servo System User Manual

Part 9

Pointing Error Model

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	Name:	Date:	Signature:
Prepared:	Dr. Dirk Libuschewski (Structural Analysis)	22.5.06	
Approved:	Klaus Willmeroth (Systems Engineer Servo)	2006-05-22	
Approved:	Dr. Konrad Pausch (Program Manager)	22-5-06	
Released:	Ralph Semmler (Document Control)	2006-05-22	

Vertex Antennentechnik GmbH
Baumstr. 50
D-47198 Duisburg
Phone +49 - 2066 -2096 -0
Fax +49 - 2066 -2096 -11
e-mail info@vertexant.de
www.vertexant.de

Table of Contents

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Release 1.3, May 2006	par. 3.1.2:	description of error application in ACU modified
	par. 3.3.2:	sign definition added
	par. 3.3.3:	formula for calculation of water vapour pressure added
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	par. 3.3.5:	new paragraph "optical refraction correction"

1. INTRODUCTION

1.1 Purpose of this Manual

This section of the Servo System User Manual contains a description of the pointing error model of the AMiBA Hexapod Telescope at Mauna Loa, Hawaii.

The pointing error model is used to eliminate known systematic pointing errors caused by non-linearities, deformations, temperature variations etc. A description of the hexapod kinematics is contained as well.

The compensation algorithms themselves are implemented in the Pointing Computer (PTC). Any accessible parameters can be modified at the PTC, see part 3 of this User Manual (description of PTC Local User Interface).

1.2 Software Identification

This Error Model Description describes the algorithms as implemented in the PTC software version:

M1002114P-2.7.

1.3 Acronym List

ACU	Antenna Control Unit
Az	Azimuth
El	Elevation
EMI	electromagnetic interference
HPC	Hexapod Computer
ICD	Interface Control Document
LCP	Local Control Panel
LUI	Local User Interface
PCU	Portable Control Unit
PLC	Programmable Logic Controller
PTC	Pointing Computer
STC	Station Computer

2. HEXAPOD KINEMATICS

The kinematics of the AMiBA telescope is a mathematical optimized kinematics of a hexapod structure which is shown in Fig. 1.

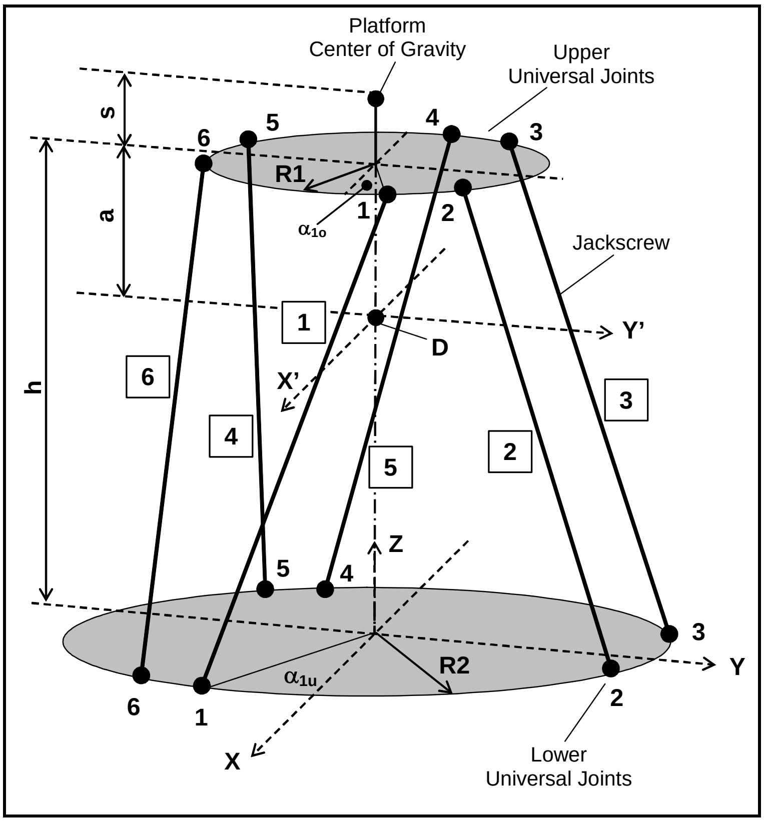

Fig. 1: Hexapod coordinate system and mount parameters

The kinematical equation of the hexapod structure is

$$L_i = \left| \left(Rz(\varphi_{az})\ Rx(\varphi_{zen})\ Rz(\varphi_{pol})\ Rz(\varphi_{az})^T \right) (mov_i - v) + v + dv - fix_i \right|, \text{ i = 1,...,6}$$

with the notations

φ_{az}	azimuth angle
φ_{zen}	zenith angle ($\varphi_{zen} = \pi/2 - \varphi_{el}$ with elevation angle φ_{el})
φ_{pol}	hexa-pol polarisation angle (alternatively obs-pol polarisation angle $\varphi_{pol\_Obs} = \varphi_{pol} - \varphi_{az}$)
v	vector of the rotation point D with v = $(0, 0, 3580)^T$ [mm]
fix	vector of the (lower) fixed point of the jackscrew with $fix_i = (xf_i, yf_i, zf_i)^T$, i = 1,...,6

mov	vector of the (upper) movable point of the jackscrew with $mov_i = (xm_i, ym_i, zm_i)^T$, i = 1,...,6
L	Jackscrew length with L_i, i = 1,...,6
dv1	manually pre-set translation movement (normally $dv1 = (0, 0, 0)^T$ [mm])
dv2	automatically translation movement to reduce the travel ranges of the universal joints

$$dv2(\varphi_{az},\varphi_{zen}) \;=\; |a| \; \frac{90° - \varphi_{el}\,[°]}{90° - \varphi_{el,\min}\,[°]} \begin{pmatrix} \sin(\varphi_{az}) \\ -\cos(\varphi_{az}) \\ 0 \end{pmatrix}$$

$$= \; |a| \; \frac{\varphi_{zen}}{\theta_{\max}} \begin{pmatrix} \sin(\varphi_{az}) \\ -\cos(\varphi_{az}) \\ 0 \end{pmatrix}$$

optimized parameter : a = 850 mm, $\theta_{max} = 60°$

dv	total translation movement with $dv(\varphi_{az},\varphi_{zen}) = dv1 + dv2(\varphi_{az},\varphi_{zen})$

rotation matrices

$$Rx(\alpha) := \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{pmatrix}$$

$$Ry(\alpha) := \begin{pmatrix} \cos(\alpha) & 0 & \sin(\alpha) \\ 0 & 1 & 0) \\ -\sin(\alpha) & 0 & \cos(\alpha) \end{pmatrix}$$

$$Rz(\alpha) := \begin{pmatrix} \cos(\alpha) & -\sin(\alpha) & 0 \\ \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

The kinematics can be different in the forward and backward transformation. Beside the topology data the forward transformation needs the angles φ_{az}, φ_{zen}, φ_{pol} and the translation movement dv1 as input data and yields the jackscrew lengths L_i, i = 1,...,6, while the backward transformation needs the jackscrew lengths L_i, i = 1,...,6 as input data and yields the angles φ_{az}, φ_{zen}, φ_{pol} and the translation movement dv1.

The global coordinate system of the AMiBA telescope together with the sky orientation is shown in Fig. 2, assuming that the mount is orientated to due North.

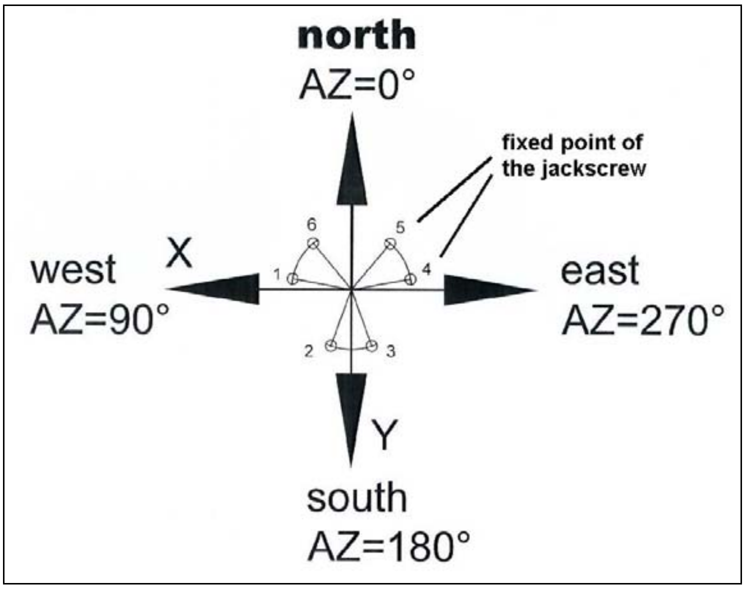

Fig. 2: Orientation of Hexapod Mount

The theoretical coordinates of the jackscrew points, which are given by an mathematical optimization calculation, are listed in Table 1.

	lower universal joints (variable “fix”)			upper universal joints (variable “mov”)		
Jack	**x [mm]**	**y [mm]**	**z [mm]**	**x [mm]**	**y [mm]**	**z [mm]**
1	R2*cos(350°)	R2*sin(350°)	0.0	R1*cos(21°)	R1*sin(21°)	4620.0
2	R2*cos(70°)	R2*sin(70°)	0.0	R1*cos(39°)	R1*sin(39°)	4620.0
3	R2*cos(110°)	R2*sin(110°)	0.0	R1*cos(141°)	R1*sin(141°)	4620.0
4	R2*cos(190°)	R2*sin(190°)	0.0	R1*cos(159°)	R1*sin(159°)	4620.0
5	R2*cos(230°)	R2*sin(230°)	0.0	R1*cos(261°)	R1*sin(261°)	4620.0
6	R2*cos(310°)	R2*sin(310°)	0.0	R1*cos(279°)	R1*sin(279°)	4620.0

Table 1 : Theoretical jackscrew points with R1=1550.0, R2=1850.0

The real coordinates of the jackscrew points have been measured during in-plant installation of the telescope in may 2004 in Duisburg, Germany by VERTEX. As a result of fabrication tolerances the actual coordinates differ slightly from the theoretical ones. They are listed in Table 2.

	lower universal joints (variable “fix”)			upper universal joints (variable “mov”)		
Jack	**x [mm]**	**y [mm]**	**z [mm]**	**x [mm]**	**y [mm]**	**z [mm]**
1	1822.8350	-320.5483	0.0	R1*cos(21°)	R1*sin(21°)	4620.0
2	632.4422	1738.0707	0.0	R1*cos(39°)	R1*sin(39°)	4620.0
3	-633.0782	1737.6624	0.0	R1*cos(141°)	R1*sin(141°)	4620.0

	lower universal joints (variable "fix")			upper universal joints (variable "mov")		
Jack	**x [mm]**	**y [mm]**	**z [mm]**	**x [mm]**	**y [mm]**	**z [mm]**
4	-1823.6568	-320.3860	0.0	R1*cos(159°)	R1*sin(159°)	4620.0
5	-1191.2478	-1416.5320	0.0	R1*cos(261°)	R1*sin(261°)	4620.0
6	1190.9897	-1417.3090	0.0	R1*cos(279°)	R1*sin(279°)	4620.0

Table 2: Actual coordinates of the jackscrew points with R1=1550.0

The mount installation on Mauna Loa differs from this symmetrical coordinates; the Az = 0 axes of the telescope as shown in Fig. 1 does not point exactly to North but is rotated by several degrees.

This Azimuth offset is must be entered at ACU, HPC and PTC as a parameter.

The following relationship applies:

$$Az_{sky} = Az_{mount} + Offset_{Az}$$

Internally, the coordinate transformations inside the three servo computer continue to use the telescope coordinate system. Commands from user or superior computer was well as position displays show the azimuth related to the "world coordinates". The position commands are converted accordingly before being entered into the hexapod coordinate transformation:

$$Az_{mount,cmd} = Az_{sky,cmd} - Offset_{Az}$$

From this point of view, all azimuth angles contained in definitions and formulae earlier in this paragraph are mount related azimuth angles.

The [mount related] coordinates of upper and lower u-joints are stored in an ASCII file on the CF memory cards of ACU, PTC and HPC.

The coordinate files of all three computers must be identical at all times!

WARNING

Any significant change in coordinates, any typos or swapped digits may lead to severe damage of the telescope because collision situations could occur without being detected by software or hardware. Utmost caution is needed when modifications to the geometry file(s) are required. Such changes should only be modified by well trained and experienced staff. The manufacturer cannot be held responsible for malfunctions and/or any damage resulting from modification of the geometry file(s).

3. POINTING ERROR MODEL

3.1 Overview

3.1.1 Components of Pointing Error Model

The pointing error model includes the following compensations:

- Compensation curves for jackscrew pitch non-linearities, based on i-plant calibration measurements for each jacks (ΔL_p).
- A compensation algorithm for jackscrew length variations due to temperature (ΔL_t).
- A compensation for non-measured length variations of a jackscrew due to rotation of the upper u-joints (ΔL_r).
- An algorithm calculating the shift of the lower u-joint coordinates due to distortion of the telescope base due to temperature.
- A compensation algorithm for deformations of the telescope including platform depending on the actual position. This compensation is derived from error tables generated during pointing calibration measurements (ΔAz_{err} , ΔEl_{err} , ΔPol_{err}).
- A compensation algorithm for RF refraction ($\Delta El_{refract}$)
- A compensation algorithm for optical refraction (required only for alignment measurements using an optical pointing telescope) ($\Delta El_{refract}$).
- A compensation algorithm for misalignment of the optical pointing telescope (ΔAz_{opt} , ΔEl_{opt})

The actual corrections are displayed at the PTC Local User Interface.

The individual compensations can be enabled and disabled separately at the PTC Local User Interface or from remote by the station computer.

3.1.2 Combination of Error Terms

The Pointing Computer will transfer the sum of all enabled corrections to the ACU, separately for jack related and telescope level corrections.

$$\begin{aligned}
\Delta L_{tot,i} &= \Delta L_{p,i} + \Delta L_{t,i} + \Delta L_{r,i} \\
\Delta Az_{tot} &= \Delta Az_{err} + \Delta Az_{opt} \\
\Delta El_{tot} &= \Delta El_{err} + \Delta El_{opt} + \Delta El_{refract} \\
\Delta Pol_{tot} &= \Delta Pol_{err}
\end{aligned}$$

The ACU will apply the corrections as follows:

a) Actual jack length (L_{act}):

$$L_{act} = L_{meas,i} + \Delta L_{tot,i}$$

b) Commanded hexapod position:

$$\begin{aligned} Az_{cmd\_forTransformation} &= Az_{cmd\_nominal} - \Delta Az_{tot} \\ El_{cmd\_forTransformation} &= El_{cmd\_nominal} - \Delta El_{tot} \\ Pol_{cmd\_forTransformation} &= Pol_{cmd\_nominal} - \Delta Pol_{tot} \end{aligned}$$

c) Actual hexapod position:

$$\begin{aligned} Az_{true} &= Az_{from\_transformation} + \Delta Az_{tot} \\ El_{true} &= El_{from\_transformation} + \Delta El_{tot} \\ Pol_{true} &= Pol_{from\_transformation} + \Delta Pol_{tot} \end{aligned}$$

This actual position is displayed at the ACU and reported as actual position to the STC. This means that the actual position always is the real position after applying all corrections and not the uncorrected mount position.

3.2 Corrections on Jack Level

3.2.1 Overview

The corrections on jack level consist of the compensations for

- jackscrew pitch error,
- temperature compensation,
- jack length measuring error depending on telescope position (due to rotation of upper u-joints)
- support cone deformation due to temperature.

All this corrections (except support cone correction) yield jack length corrections ΔL_1 … ΔL_6 for each of the jackscrews 1…6. On the other hand the special case effects a coordinate change of the lower universal joints which also can be interpreted as a length change of the jackscrews. All modules are described in the following chapters.

3.2.2 Jackscrew pitch error

The telescope positioned is determined by measuring the positions of the six jackscrew actuators. Since not the real length of the jackscrews is measured but only the rotation, any jack pitch error (e.g. machining errors, non-linearities etc.) directly leads to a telescope positioning error.

In order to be able to compensate for this error each jackscrew has undergone an in-plant calibration measurement. A correlation function (see Fig. 3) between the linear movement of the jackscrew and the encoder readout has been derived for each jackscrew.

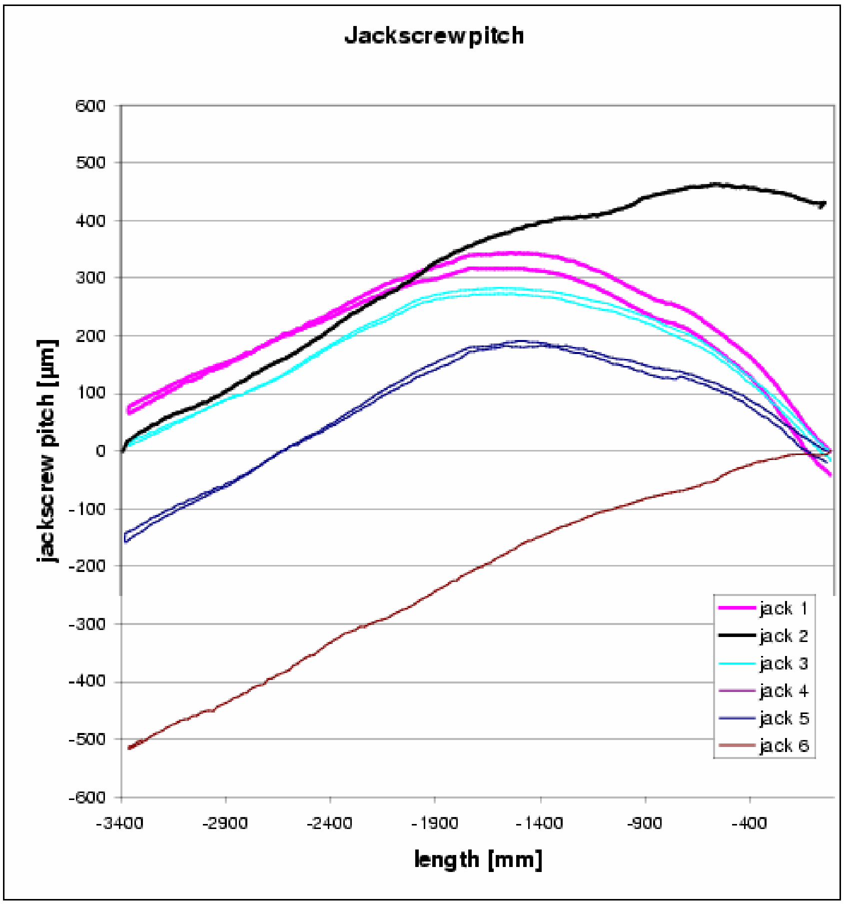

Fig. 3: Error curves for jackscrew pitch

Each measurement curve in Fig. 3 can be described by a polynomial of the order 10 in the form $f(x) = \sum_{i=0}^{10} a_i \; x^i$. The vector a of the coefficients for each jackscrew is listed in Table 3.

a	jackscrew 1	jackscrew 2	jackscrew 3	a
a_0	$-2.024509761765160*10^{1}$	$4.254599813289640*10^{2}$	$-1.424616467483780*10^{1}$	a_0
a_1	$-4.690421834325520*10^{-2}$	$-2.015506873855310*10^{-2}$	$-3.014122368016800*10^{-1}$	a_1
a_2	$3.175818812949300*10^{-3}$	$-1.279223138765940*10^{-4}$	$5.333730182112170*10^{-4}$	a_2
a_3	$1.000966699300860*10^{-5}$	$-2.079059533885010*10^{-6}$	$1.767559120263330*10^{-6}$	a_3
a_4	$1.541352099930610*10^{-8}$	$-6.590341383524090*10^{-9}$	$2.504907224531590*10^{-9}$	a_4
a_5	$1.387921160762620*10^{-11}$	$-9.238622036561910*10^{-12}$	$2.285806763018910*10^{-12}$	a_5
a_6	$7.764892416501680*10^{-15}$	$-7.095505201937470*10^{-15}$	$1.446531162237440*10^{-15}$	a_6
a_7	$2.743812116375030*10^{-18}$	$-3.198287869016120*10^{-18}$	$6.245759670530750*10^{-19}$	a_7
a_8	$5.973058848219020*10^{-22}$	$-8.457849525584240*10^{-22}$	$1.714087876766300*10^{-22}$	a_8
a_9	$7.325619589449050*10^{-26}$	$-1.217131472371950*10^{-25}$	$2.645713864558710*10^{-26}$	a_9
a_{10}	$3.877049825835910*10^{-30}$	$-7.368087558944830*10^{-30}$	$1.731246066850530*10^{-30}$	a_{10}
a	jackscrew 4	jackscrew 5	jackscrew 6	a
a_0	$2.743324175636780*10^{1}$	$-9.120596249290690*10^{0}$	$-8.464647627231470*10^{-2}$	a_0
a_1	$1.816390007961940*10^{-2}$	$2.994017883033060*10^{-2}$	$1.399391192743870*10^{-1}$	a_1
a_2	$2.040482864105740*10^{-3}$	$1.853475595088450*10^{-3}$	$1.296102525136170*10^{-3}$	a_2
a_3	$6.306703070241420*10^{-6}$	$4.707048964999170*10^{-6}$	$5.695909876093460*10^{-6}$	a_3
a_4	$9.461016317632950*10^{-9}$	$5.301560895763430*10^{-9}$	$1.109389698870550*10^{-8}$	a_4
a_5	$8.105379713701580*10^{-12}$	$2.787891685747700*10^{-12}$	$1.187703984708340*10^{-11}$	a_5
a_6	$4.193397675987190*10^{-15}$	$3.403289908214870*10^{-16}$	$7.580116027803620*10^{-15}$	a_6
a_7	$1.320217138374700*10^{-18}$	$-3.342955508378500*10^{-19}$	$2.961352291320270*10^{-18}$	a_7
a_8	$2.423328419428810*10^{-22}$	$-1.739067723782910*10^{-22}$	$6.948301798710590*10^{-22}$	a_8
a_9	$2.285716445585560*10^{-26}$	$-3.372908043046730*10^{-26}$	$8.991790206208470*10^{-26}$	a_9
a_{10}	$7.708311059986410*10^{-31}$	$-2.432377395612230*10^{-30}$	$4.932382220905220*10^{-30}$	a_{10}

Table 3: Vector ‘a’ for each jackscrew

Finally the measurement curves must shifted depending on of the real jackscrew length L [mm] and the characteristic measurement data (see Fig. 4)

C1 jackscrew length,
C2 reference switch,
C3 measurement limit extended jackscrew,
C4 measurement retracted jackscrew,
C5 movement of the curve with C5 = -f(C2),

so that the jackscrew pitch error can be calculated by

$$\Delta L\ [mm] = \left(f(L - C1 + C2) + C5\right)\ 10^{-3}\ .$$

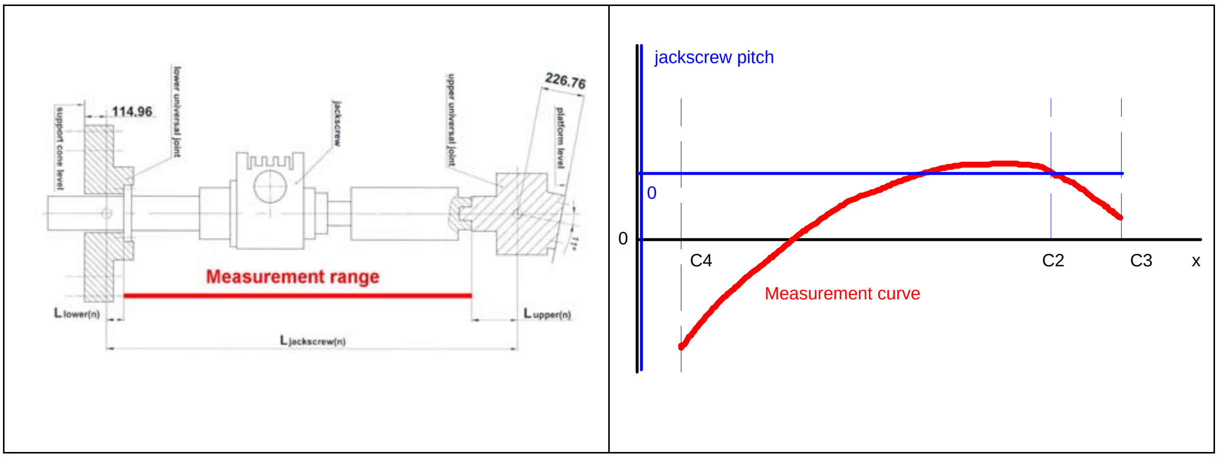

Fig. 4: Jackscrew with measurement curve

The measurement curve is situated in the range of C4 < L-C1+C2 < C3. The data C1…C5 are listed in Table 4.

Jack	C1 [mm]	C2 [mm]	C3 [mm]	C4 [mm]	C5 [µm]
1	6150.366	-36.624	-19.1972	-3359.1970	14.7324
2	6149.009	-86.603	-47.7033	-3407.7029	-427.2679
3	6149.542	-38.486	-19.7907	-3359.79012	1.9514
4	6149.961	-25.151	-27.3491	-3367.3489	-28.1705
5	6150.103	-56.476	-35.8999	-3375.8999	5.6953
6	6150.360	-20.820	-17.6202	-3357.6202	2.4857

Table 4 : Correction factors for each jackscrew

The coefficient vector ‘a’ is coded in the hexapod software and the correction variables C1 until C5 are stored in an external file. This file has to be replaced along with the related jackscrew if a jackscrew needs to be exchanged.

The correction algorithm yields length corrections ΔL_{p1} until ΔL_{p6}.

3.2.3 Temperature Compensation

The varying temperature of the different jackscrews with the length L produces a length change ΔL_t of each jackscrew compared to the length at calibration temperature. Taking into account the material specific thermal expansion coefficient $\alpha = 12.0 * 10^{-6}$ [1/K] and the temperature difference ΔT between the individual jackscrews, which will be measured and averaged by three temperature sensors (P_{sens1}, ΔT1), (P_{sens2}, ΔT2), (P_{sens3}, ΔT3) along the jackscrew (see Fig. 5),

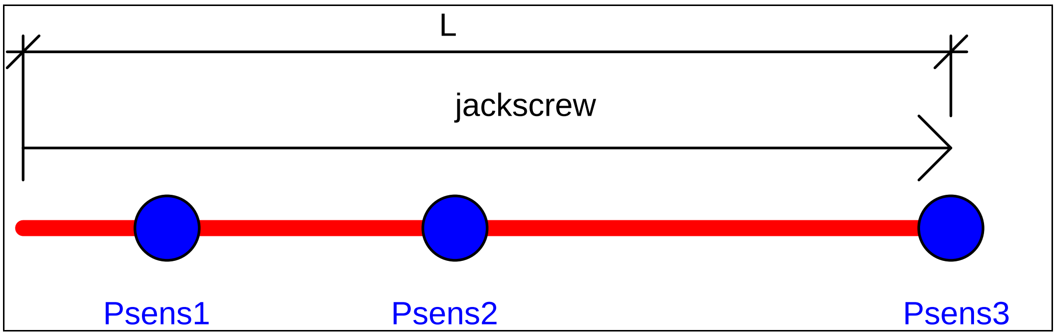

Fig. 5: Jackscrew with temperature sensors

the length change results approximately in a linear temperature characteristics function

$$f(x) = \begin{cases} \Delta T1 & x \le P_{sens1} \\ \dfrac{\Delta T2 - \Delta T1}{P_{sens2} - P_{sens1}} x + \dfrac{\Delta T1 \; P_{sens2} - \Delta T2 \; P_{sens1}}{P_{sens2} - P_{sens1}} & P_{sens1} < x \le P_{sens2} \\ \dfrac{\Delta T3 - \Delta T2}{P_{sens3} - P_{sens2}} x + \dfrac{\Delta T2 \; P_{sens3} - \Delta T3 \; P_{sens2}}{P_{sens3} - P_{sens2}} \quad if & P_{sens2} < x \le P_{sens3} \\ \Delta T3 & x > P_{sens3} \end{cases}$$

to $$\Delta L_t = \int_0^{P_{sens1}} \alpha \; f(x) \; dx + \int_{P_{sens1}}^{P_{sens2}} \alpha \; f(x) \; dx + \int_{P_{sens2}}^{P_{sens3}} \alpha \; f(x) \; dx .$$

Calibration temperature is +17°C, so

$$\Delta T = T_{sens} - 17°C.$$

With the position of the sensors Psens1=122.0 mm, Psens2=1250.0 mm, Psens3=L_i and the readouts of the temperatures at the sensors, the results of the module temperature correction are the correction lengths ΔL_{t1} … ΔL_{t6}.

3.2.4 Jackscrew Rotation Error

Each jackscrew spindle rotates with the angle β_z (see also Fig. 6) relative to the jackscrew nut when tilting and rotating the telescope mount. Because of the spindle thread a jackscrew length change can occur which is not detected by the encoder on the still standing worm gear shaft. This influence is calculated by a mathematical algorithm derived from the kinematics of the jackscrew at any position.

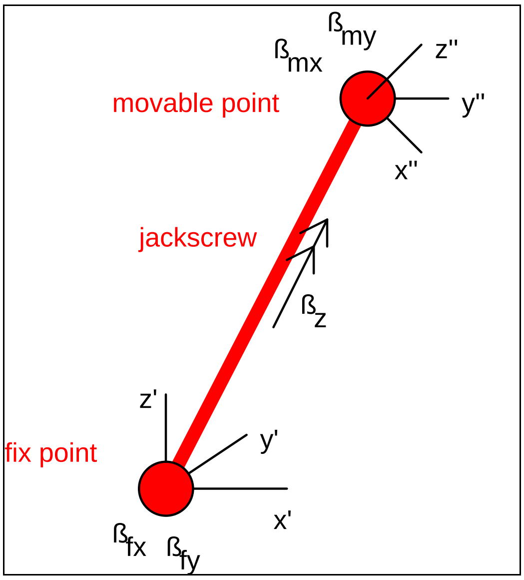

Fig. 6: Rotation of the jackscrew

Each jackscrew kinematics consists of the five degrees of rotations β_{fx}, β_{fy}, β_{mx}, β_{my} and β_z. A special algorithm calculates the essential data β_z. With a jackscrew pitch of p = 20 mm/rotation and the basis rotation angle $\beta_{z,basis}$ (is equal to β_z in the hexapod basis position) the jackscrew length error by rotation of the jackscrew against the fixed nut is

$$\Delta L_r = \left(\beta_{z,basis} - \beta_z\right) \frac{p}{2\ \pi}.$$

The algorithm is coded in the hexapod software and the results are the correction lengths ΔL_{r1} … ΔL_{r6}.

3.2.5 Support Cone Compensation Mode

The coordinates of the 6 lower (fixed) universal joints has been measured during in-plant assembly of the AMiBA Telescope in May 2004 at an ambient temperature of 17° C. The x and y coordinates vary with the temperature of the support cone. This error is taken into account by the formulae

$$x_{new} = x * \alpha * (T - T_0)$$

$$y_{new} = y * \alpha * (T - T_0)$$

with the notations

α	specific thermal expansion coefficient with $\alpha = 12.0 * 10^{-6}$ [1/K],
T	average value of the temperature which is measured by several sensors at the cone,
T_0	basis measurement temperature of 17° C,
x, y	coordinates of the lower (fixed) universal joints (see Table 2, page 5).

Together with the readout temperatures at the sensors and the original x, y coordinates of the lower universal joints at a temperature of 17° C, the results of the module support cone compensation mode are corrected x, y coordinates for the 6 lower universal joints.

3.3 Corrections on Telescope Level

3.3.1 Overview

The corrections on telescope level consist of the compensations for

- error model for telescope and platform deformations,
- compensation algorithm for RF refraction
- compensation algorithm for optical refraction.

All this corrections (except support cone correction) yield position corrections $\Delta\varphi_{az}$, $\Delta\varphi_{el}$ and $\Delta\varphi_{pol}$.

3.3.2 Telescope Error Model

The idea of the telescope correction mode is to measure the telescope position errors $\Delta\varphi_{az}$, $\Delta\varphi_{el}$ and $\Delta\varphi_{pol}$ at different points on the sky by astronomical observation of well known targets. All measurement points together make up a measurement grid. For positions between the data points the delta positions can be calculated by interpolation.

For each data point, the hexapod position (Az, El, Pol) and the measured pointing errors (dAz, dEl, dPol) are entered into a file named inter_un.dat (see sample file in Table 5). The measurements make up an irregular grid of one sector of the sky. For a good pointing accuracy both the sector size and the number of measurements should be as large as possible. In addition, the measurements should be made at different polarisations.

Definition of sign of pointing error:

- Nominal position of object: $(Az_N \mid El_N \mid Pol_N)$
- The object has been found at (position display at ACU / PTC): $(Az_F \mid El_F \mid Pol_F)$
- Error to be entered into table
  at position $(Az_N \mid El_N \mid Pol_N)$
  measured pointing error $(Az_F - Az_N \mid El_F - El_N \mid Pol_F - Pol_N)$

```
Transform measurement data by an irregular grid to an regular grid
==================================================================

calculation for an regular grid
azimuth area [degree]           0.00     360.00   step   5.00
elevation area [degree]        30.00      90.00   step   5.00
polarisation area [degree]    -25.00      10.00   step   5.00

measurement data, irregular grid
    Az             El             Pol            dAz            dEl            dPol
   0.00000000    30.00000000   -30.00000000     1.00000000     1.00000000     1.00000000
  20.00000000    30.00000000   -30.00000000     5.00000000     1.00000000     2.00000000
  40.00000000    30.00000000   -30.00000000     4.00000000     1.00000000     3.00000000
  60.00000000    30.00000000   -30.00000000     3.00000000     1.00000000     4.00000000
  80.00000000    30.00000000   -30.00000000     6.00000000     2.00000000     6.00000000
 160.00000000    30.00000000   -30.00000000     3.00000000     7.00000000     4.00000000
 180.00000000    30.00000000   -30.00000000     4.00000000     2.00000000     1.00000000
 200.00000000    30.00000000   -30.00000000     6.00000000     3.00000000     4.00000000
 220.00000000    30.00000000   -30.00000000     7.00000000     4.00000000     5.00000000
 100.00000000    30.00000000   -30.00000000     7.00000000     3.00000000     7.00000000
 120.00000000    30.00000000   -30.00000000     3.00000000     4.00000000     2.00000000
 140.00000000    30.00000000   -30.00000000     2.00000000     6.00000000     3.00000000
```

Table 5: Unsorted position measurements in file inter_un.dat

The actual position for Pol in the both irregular and regular grids must always be entered as Hex-Pol (polarisation related to the hexapod mount).

After the measurements are done the irregular grid must be transformed into a regular grid and the result is saved in a file named inter.dat (see sample in Table 6).

The file must contain the characteristic data of the regular grid in lines 2…4 as shown in the sample file. This includes:

- upper and lower limits of measured sector in Az, El and Pol
- step size for regular grid in Az, El and Pol.

The grid steps may be different for Az, El and Pol. The interpolation algorithm does not require a particular step size. However, the maximum number of lines in this file may not exceed 100,000.

A possible mathematical algorithm to get a regular grid is known as Shepard method. It can be used as stand-alone software. This method (and of course all other mathematical methods) is only effective inside the measurement sector. Interpolations for positions outside the measurement sector may be inaccurate.

Activating the telescope error model correction requires a file inter.dat. This must be saved on the disk on the PTC flash card in the same directory as the executable software. To read a new file inter.dat the PTC must be re-bootet.

The correction software calculates by interpolation the position errors $\Delta\varphi_{az}$, $\Delta\varphi_{el}$ and $\Delta\varphi_{pol}$ as a function of the present telescope position. Therefore the regular grid has a great computer time advantage adverse the irregular grid. The linear interpolation algorithm searches the cube of the neighbouring positions in the grid which encloses the actual position, and interpolates the position errors assigned to each corner of the cube. The file inter.dat must contain identical lines for Az = 0 deg and Az = 360 deg.

The telescope error model yields position corrections ΔAz_{err}, ΔEl_{err} and ΔPol_{err}.

```
Calculation for an regular grid
azimuth area [degree]         0.0000   360.0000  step     5.0000
elevation area [degree]      30.0000    90.0000  step     5.0000
polarisation area [degree]  -25.0000    10.0000  step     5.0000

      Az             El             Pol            dAz            dEl            dPol
    0.00000000    30.00000000   -25.00000000     0.06819019    -0.00858209     0.00000000
    0.00000000    30.00000000   -20.00000000     0.06818528    -0.00858367     0.00000000
    0.00000000    30.00000000   -15.00000000     0.06818039    -0.00858527     0.00000000
    0.00000000    30.00000000   -10.00000000     0.06817552    -0.00858688     0.00000000
    0.00000000    30.00000000    -5.00000000     0.06817067    -0.00858849     0.00000000
    0.00000000    30.00000000     0.00000000     0.06816586    -0.00859011     0.00000000
    0.00000000    30.00000000     5.00000000     0.06816108    -0.00859174     0.00000000
    0.00000000    30.00000000    10.00000000     0.06815635    -0.00859336     0.00000000
    0.00000000    35.00000000   -25.00000000     0.06829306    -0.00857819     0.00000000
    0.00000000    35.00000000   -20.00000000     0.06828835    -0.00857977     0.00000000
    0.00000000    35.00000000   -15.00000000     0.06828363    -0.00858136     0.00000000
    0.00000000    35.00000000   -10.00000000     0.06827888    -0.00858296     0.00000000
    0.00000000    35.00000000    -5.00000000     0.06827412    -0.00858458     0.00000000
    0.00000000    35.00000000     0.00000000     0.06826935    -0.00858620     0.00000000
    0.00000000    35.00000000     5.00000000     0.06826458    -0.00858782     0.00000000
    0.00000000    35.00000000    10.00000000     0.06825981    -0.00858946     0.00000000
    0.00000000    40.00000000   -25.00000000     0.06839662    -0.00857429     0.00000000
    0.00000000    40.00000000   -20.00000000     0.06839212    -0.00857586     0.00000000

..................................................................
..................................................................
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  360.00000000    85.00000000   -25.00000000     0.11690180    -0.00683586     0.00000000
  360.00000000    85.00000000   -20.00000000     0.13483681    -0.00670948     0.00000000
  360.00000000    85.00000000   -15.00000000     0.16171136    -0.00655411     0.00000000
  360.00000000    85.00000000   -10.00000000     0.20329068    -0.00648106     0.00000000
  360.00000000    85.00000000    -5.00000000     0.28139628    -0.00676227     0.00000000
  360.00000000    85.00000000     0.00000000     0.37440990    -0.00703623     0.00000000
  360.00000000    85.00000000     5.00000000     0.28172032    -0.00677584     0.00000000
  360.00000000    85.00000000    10.00000000     0.20456258    -0.00656923     0.00000000
  360.00000000    90.00000000   -25.00000000     0.12713996    -0.00680790     0.00000000
  360.00000000    90.00000000   -20.00000000     0.14697311    -0.00664064     0.00000000
  360.00000000    90.00000000   -15.00000000     0.17562134    -0.00644921     0.00000000
  360.00000000    90.00000000   -10.00000000     0.21738251    -0.00631872     0.00000000
  360.00000000    90.00000000    -5.00000000     0.27689824    -0.00643678     0.00000000
  360.00000000    90.00000000     0.00000000     0.31867511    -0.00665926     0.00000000
  360.00000000    90.00000000     5.00000000     0.27740887    -0.00645507     0.00000000
  360.00000000    90.00000000    10.00000000     0.21882686    -0.00639312     0.00000000
```

Table 6: Sample file inter.dat

3.3.3 RF Refraction Correction

The PTC also compensates for atmospheric radio refraction[1]. Enabling/disabling is possible at the PTC Local User Interface.

The algorithm used is taken from 'Astrophysical Quantities', by C.W. Allen (3rd edition, page 124), and is :

$N = 1 - (7.8e-5 * P + 0.39 * e/T)/T$
$ref0 = (N*N - 1)/2*N*N$
$\Delta El_{refract} = ref0/tan(alt)$

where	P	atmospheric pressure in mb (hPa)
	e	water vapour pressure in mb (hPa)
	T	temperature in Kelvin
	alt	altitude

The correction $\Delta El_{refract}$ is to be <u>added</u> to the true altitude to give the apparent altitude.

Actual weather data can be transferred by the station computer to the PTC in order to keep the compensation as accurate as possible.

Calculation of water vapour pressure (e) from relative humidity:

$e = RH/100 * ES$

$ES = c_0 * 10**[c_1*Tc / (c_2 + Tc)]$

where: e = water vapour pressure in mb (hPa)
RH = relative humidity in %
ES = saturation pressure of water vapour in mb (hPa)
Tc = temperature, deg C
c_0 = 6.1078
c_1 = 7.5
c_2 = 237.3

---

[1] Algorithms provided by ASIAA

3.3.4 Misalignment of Optical Telescope

This correction is only required during observations with the optical pointing telescope. It compensates for any misalignments of this device compared to the pointing direction of the main telescope.

The (x,y,z)-right hand frame of an optical telescope is positioned on the AMiBA platform, whereas the z-axis is normal to the platform and the y-axis the reference line for $\varphi_{pol} = 0$ degree. With the notations

Hx	angle in the x-z plane (rotation around the y-axis, for small angles it points along the x-axis)
Hy	angle in the y-z-plane

the pointing correction angles are[2]

$$\Delta Az_{opt} = \frac{Hx \;\cos(\varphi_{az} + \varphi_{pol}) \;+\; Hy \;\sin(\varphi_{az} + \varphi_{pol})}{\cos(\varphi_{el})}$$

$$\Delta El_{opt} = Hy \;\cos(\varphi_{az} + \varphi_{pol}) \;-\; Hx \;\sin(\varphi_{az} + \varphi_{pol})\,.$$

The parameters Hx and Hy can be entered at the PTC Local User Interface, see part 3 of this manual.

The correction algorithm yields position corrections ΔAz_{opt} and ΔEl_{opt}. There is no error in polarization.

---

[2] Formula provided by ASIAA

3.3.5 Optical Refraction Model

The optical refraction is required only for alignment measurements using an optical pointing telescope. During normal operation this refraction should be disabled. Enabling/disabling is only possible at the PTC Local User Interface.

Correction formula:

$$\Delta\Phi_{\mathrm{Re}\,frOPT} = 1.2 * \frac{60.101 * \tan(ZD) - 0.0668 * \tan^{3}(ZD)}{(180/\,pi) * 3600} * \frac{PMB}{1013.2} * \frac{283.15}{TDK}$$

TDK: Ambient temperature [K]
PMB: Atmospheric pressure [mbar]
ZD: Distance from zenith [rad] = (90 degr - Φ_{El}) * π/180

The formula yields REF in radians.

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