National Centre for Radio Astrophysics

Internal Technical Report

GMRT/SERVO/PC104/005-DEC-2011

Study and Analysis of Servo Elevation Axis Software and Hardware Limit hit Problem

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Contents

List of Figures

List of Tables

1. Introduction

For a parabolic structure, 45m GMRT antennas are more prone to mechanical damages than other small antennas, due to their huge structure. The size of GMRT antennas restricts the complete motion of the antenna in both axes in the view of antenna safety. But, this issue becomes more dangerous in elevation axis when the antenna is moving towards ground, as there is a probability that the antenna may hit the ground under certain condition.

To protect 45m GMRT antennas from such damages, three limits have been set for both axes of all the antennas. The elevation limits are,

- Software Limit (Online) 17.00 degrees
- Servo Pre Limit (Soft Limit) 16.50 degrees
- Hardware Limit 15.50 degrees (varies with antenna)

But, due to certain reasons like system dynamics, wind etc. the antenna may hit one of these limits. GMRT online computer system has been designed in such a way that any of these conditions is detected and a call sheet is generated for that antenna immediately.

A similar kind of problem was observed on 9th Dec 2011 and 13 Dec 2011, with antennas W02, E04 respectively, during which software and hardware limits were hit. In order to analyze the problem, a series of experiments were conducted on antenna W02 in the month of Dec 2011, trying to simulate those conditions and understand the fault. This document describes the set of experiments performed and the results obtained.

2. Description

The main aim of the experiments conducted, was to simulate the conditions which led to limit hit on 9th Dec 2011 W02, E04, and on 13th Dec 2011 on W06. Another part of experiment included tests to find the overshoot of all the antennas. This comprised of a test on W02 and E04 using HHT at the antenna base and tracking all antennas from various position in elevation near software limit. After this, a set of experiments were conducted on 29 Dec 2011 using PC104 servo computer at antenna base to detect the possible fault in the existing communication link between SSC and ABC. The plots for various tests are included in data analysis.

3. EL Axis State Machine and Operational Commands

3.1 Simplified EL Axis State Machine

State machine is a model, which defines the different stages of a machine and its possible transitions (set of possible inputs and expected outputs) between those stages in a machine. Each stage of a state machine is unique.

Figure 3.1 shows the simplified state machine for GMRT antenna elevation axis. The various states for the state machines are the user commands (discussed in next chapter). While, the state transitions depend on the operational interlocks, operational commands from the host computer (i.e. ABC) and timeouts from the various software timers. Table 1 gives different combination of operational commands which changes the machine states.

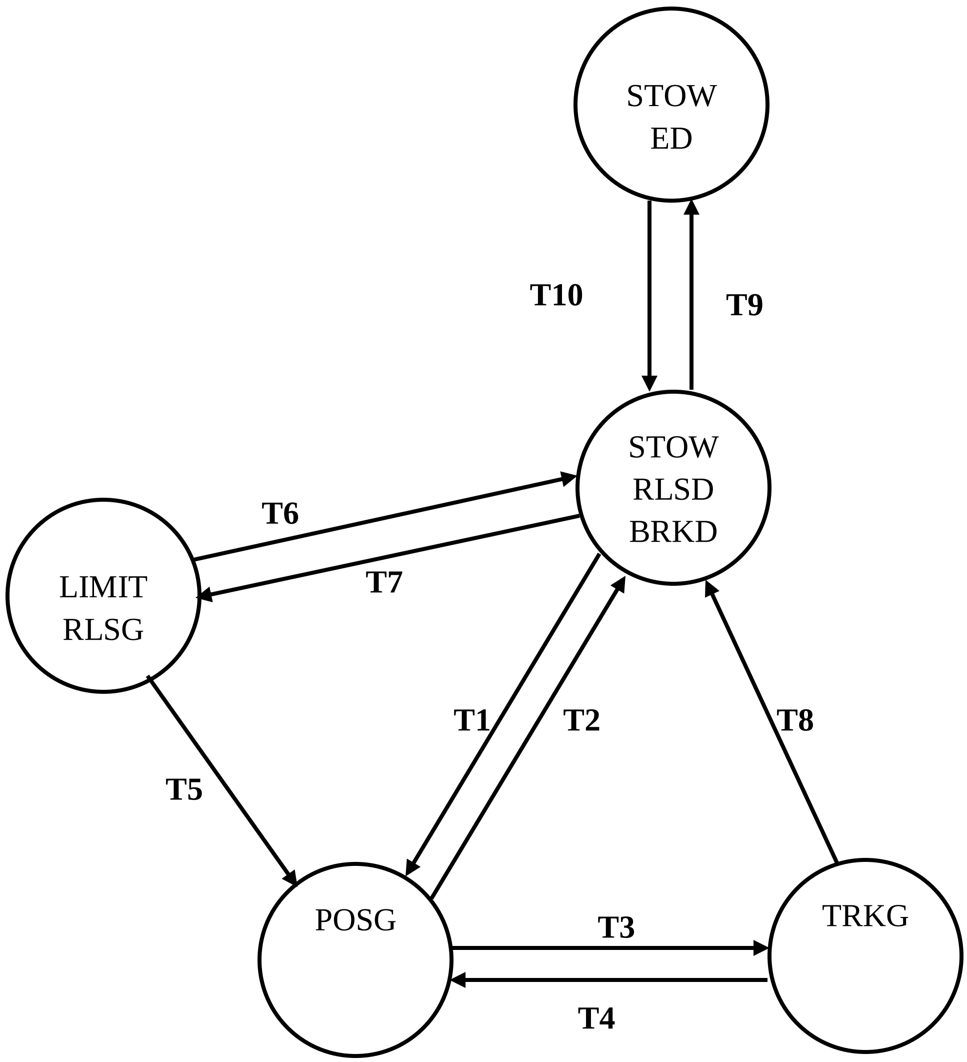

Figure 3-1 Simplified EL Axis State Machine

TRANSITIONS		COMMANDS LIST / EVENTS
T1	:	HOLD | POSN | COLDSTART
T2	:	CLOSE | STOP | PROCESS FAULTS
T3	:	TRACK
T4	:	ABORT | HOLD
T5	:	LIMIT RELEASING
T6	:	ABORT | TIMER EXPIRY | PROCESS FAULT
T7	:	HOLD & LIMIT ACTIVE
T8	:	STOP | PROCESS FAULT
T9	:	CLOSE | STOW
T10	:	STOW RLS | COLD START

Table 3-1 Operational Commands and State Transitions

3.2 Operational Commands

When the antenna is under the control of SSC (Station Servo Computer), i.e. during local and remote mode, it implements all interlocks in the software. It uses encoder feedback information to control the closed loop position.

In *Manual mode*, control commands are given from console mounted position POTs thus, allowing user (individual at the antenna base) the facility of controlled operation, while in *Remote mode*, all the commands are given from ABC through the serial link neglecting all manual mode commands. Description of local and remote mode commands are given below,

3.2.1 Hold Command

During HOLD command, SSC holds the axis at current position with position loop active. The sequence of operations on receiving the HOLD command from host is,

1. Checks to see that no disabling conditions exist in that particular axis.
2. Turns the drives ON and releases brakes.
3. Wait on a timer (AXIS ON DELAY) to check that drive is ready and releases the brakes.
4. On time-out it aborts the HOLD Command, otherwise enables position loop controller with,
   demand_target_angle = current_angle.
5. Updates the final state of antenna to POSITIONING and continues to correct against actual angle variation due to wind and other disturbances. On detection of any conditions such as over-

current, over-speed or high wind velocity axis is turned off, brakes are applied and POSITIONING state is exited.

6. By issuing STOP command (i.e. de-energizing the amplifiers and applying brakes) it goes back to STRLSDBKD state.

3.2.2 Position Command

On receiving position command, the SSC moves the antenna to commanded position and holds it there. The following sequences of operations are performed on receiving the POSITION command for specific axis from host,

1. Checks to see that no disabling conditions exist in that particular axis.
2. The demand angle is valid (i.e. not in limit region).
3. If antenna state is STRLSDBKD then it turns the drives ON and releases brakes. Then, it waits on a timer (AXIS ON DELAY) to check that drive is ready and brakes are released. Finally it updates the antenna state to POSITIONING.
4. If antenna state is POSITIONING, then it loads the target angle and activate the position loop compensator.
5. Position loop controller fed with an error (i.e. position error = target angle - current angle).
6. Position loop compensator output increases until current angle reaches target angle (i.e. position error is 0.0 deg).
7. SSC continuously monitors the axis disabling conditions during positioning and takes necessary action. As earlier, STOP command aborts POSITIONING state and brings to STRLSDBKD.

3.2.3 Track Command

SSC is capable of driving the antenna to follow a trajectory of angle vs. time co-ordinates. The desired trajectory is fed as target angle and target time. For this command SSC calculates intermediate angles for every 100msec time step and calculates error from this.

The host computer (i.e. ABC) provides desired trajectory information at every 30sec interval. A single element queue is maintained by the SSC so that the ABC can give a new pair of co-ordinates in advance. These new co-ordinates will be picked up by the SSC from the queue on reaching the previously established target time.

The following steps are performed by the SSC to drive the antenna in the specified trajectory –

1. Previous state of antenna is checked, as it should be POSITIONING for track commands.
2. Validity checks are performed on the target_angle and target_time. SSC puts no restrictions to target_angle but for target_time, it should be two hours later than the current time.
3. After validation SSC calculates the intermediate demand positions as follows,

$$delta\_position = \mathrm{sample\_time} * \frac{target\_angle - current\_angle}{\mathrm{target\_time} - \mathrm{current\_time}}$$

4. This Delta_position added to current_angle for every 100msec and position error is generated accordingly.

5. Then, the position loop compensator generates the speed demand accordingly and sends it to next stage. The following figure.2 shows the intermediate demand positions for every 100msec.
6. At the end of target_time it takes new command from the track queue and processes it.
7. While processing the track command.
   a) If HOLD/ABORT command comes from host it will discards the currently running track command and clears track queue, and enters into POSITIONING state.
   b) If STOP command comes from host it discards the currently running track command and clears track queue, and enters into STRLSDBKD state.

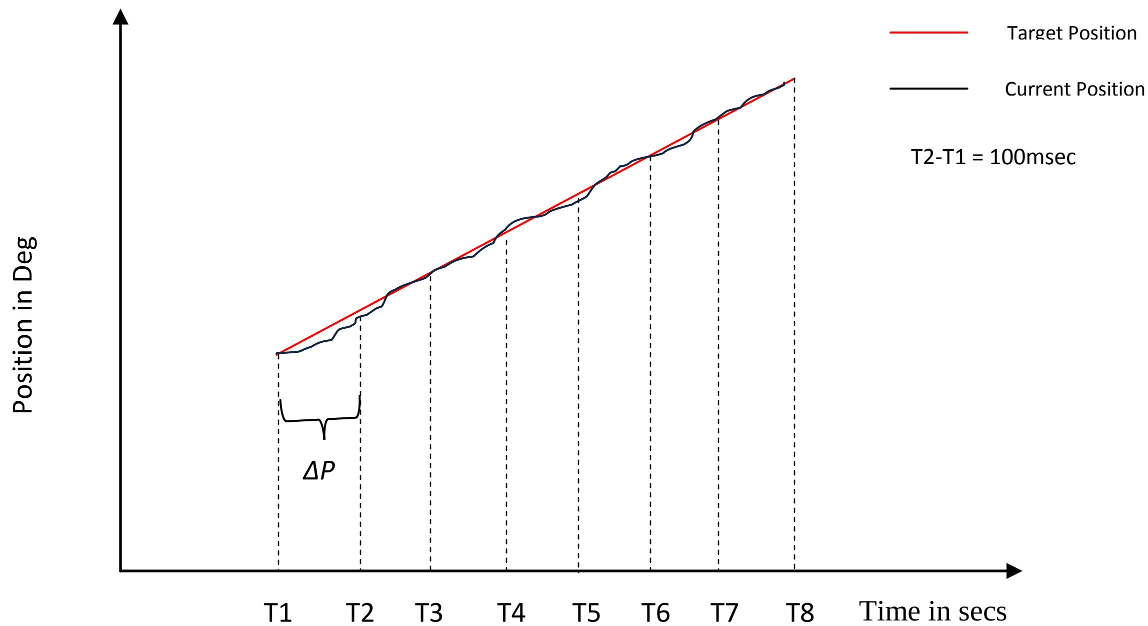

Figure 3-2 Tracking Trajectory Calculation

3.2.4Abort Command

ABORT command is accepted by SSC only when the antenna is either in POSITIONING state or TRACKING state, upon receiving the ABORT command from host, SSC performs the following operations to go back to stand by with position loop enabled.

1. If antenna state is POSITIONING servo program clears the target_angle and updates the current_angle as a target_angle and it computes the safe stop angle from the current velocity of antenna and maximum acceleration of specific axis and generates the final stop position.
2. If antenna is in TRACKING state, servo program discards the currently running track and updates the current_angle as a target_angle, as well as it clears the track queue. Then, servo computes the safe stop angle from the current velocity of antenna and maximum acceleration of specific axis and generates the safe stop angle.

The following motions equation is used to calculate the safe stop position

$$v^2 = u^2 + 2as$$

Where,

$$v = final\ velocity\ (d/s)$$
$$u = initial\ velocity\ (d/s)$$
$$a = axis\ accleration\ (d/s\hat{}2)$$
$$s = position\ displacement\ (d)$$

In our case final velocity should be zero, by sub-suiting $v = 0$ in above equation,

$$position\_displacement\ (\mathrm{s}) = \frac{u^2}{2a} \qquad 3.1$$

This position displacement can be added to current angle to generate target position to stop the axis, depends on the direction of antenna motion, the sign of the position displacement will change,

$$safe\_stop\_position = current\_position\ + position\_displacement\ (\mathrm{s})\ 3.2$$

4. Data Analysis and Plots

The following experiments were conducted on W02 antenna on 28-Dec-2011 and 29-Dec-2011 using PC104 with its data logging feature for different servo parameters like encoder angles, motor currents, speeds etc. along with the servo communication mail box for host commands.

The tests done on 20-Dec-2011 and 22-Dec-2011 included moving all antennas from 20 deg, 40 deg and 70 deg to 17 deg from CEB. The data for all available 22 antennas were plotted and are depicted in data analysis. Also, antennas W02 and E04 were moved in elevation from different positions (ranging from 40 degrees to 19 degrees) to 17 degrees using HHT at the antenna base. These tests were conducted to see the variation of overshoot near the software limit. The corresponding plots are shown in appendix.

During the experiments on 28-Dec-2011 and 29-Dec-2011, W02 antenna was made to track the sources, which were close to limit region in EL axis, by giving the repetitive SETABCT command from online we simulated the servo software limit hit condition. Tests were done to see the effect of command SETABCT on target_position of antenna.

Also, the antenna was moved from 20°,19° and 18°to 17° in both track and position mode to check for limit hitting. Various plots and command logs are shown in the succeeding figures.

4.1 Analysis during tracking with repetitive SETABCT

The following listing gives comparison between PC104 commands from ABC and Online Commands,

PC104 Command Log:

Dec	2917:12:12B,B,+220:14:34,+017:00:00		
Dec	2917:12:13P		
Dec	29	17:13:13	R,17:12:15,29-12-2011
Dec	29	17:12:15	D,B,17:12:29,+220:12:23,+017:00:00
Dec	29	17:12:16	D,B,17:12:59,+220:13:56,+017:00:00
Dec	29	17:12:28	$0 1$1 1
Dec	29	17:12:37	D,B,17:13:29,+220:15:30,+017:00:00
Dec	29	17:12:53	P
Dec	29	17:12:53	R,17:12:53,29-12-2011
Dec	29	17:12:53	D,B,17:12:59,+220:13:56,+017:00:00
Dec29		17:12:54	D,B,17:13:29,+220:15:30,+017:00:00
Dec29		17:12:58	$0 1$1 1
Dec29		17:13:01	P
Dec29		17:13:03	R,17:13:03,29-12-2011
Dec29		17:13:03	D,B,17:13:29,+220:15:30,+017:00:00
Dec29		17:13:04	P
Dec29		17:13:04	R,17:13:04,29-12-2011
Dec29		17:13:04	D,B,17:13:59,+220:17:10,+017:00:00
Dec29		17:13:04	D,B,17:13:29,+220:15:30,+017:00:00
Dec29		17:13:06	D,B,17:13:59,+220:17:10,+017:00:00
Dec29		17:13:06	P
Dec29		17:13:06	R,17:13:06,29-12-2011
Dec29		17:13:06	D,B,17:13:29,+220:15:30,+017:00:00
Dec29		17:13:07	P
Dec29		17:13:09	R,17:13:09,29-12-2011
Dec29		17:13:09	D,B,17:13:59,+220:17:10,+017:00:00
Dec29		17:13:10	D,B,17:13:29,+220:15:30,+017:00:00
Dec29		17:13:11	D,B,17:13:59,+220:17:10,+017:00:00

D – Track Command, $0 1,$1 1 expiry of az el track cmd

P – ABORT Command, B – Both Axis,

R-Set TOD command, B – POSITION command

Online Command Log:

17:12:13	subac3.5:subac3
17:12:13	subac3.5: LOAD NEW SRC SPECIFIC TRAK PARA
17:12:15	user3.5: ABC SET TIME17:12:15,29-12-2011
17:12:42	subac3.5: subac3
17:12:53	user3.5: ABC SET TIME17:12:53,29-12-2011
17:13: 3	user3.5: ABC SET TIME17:13:03,29-12-2011
17:13: 4	user3.5: ABC SET TIME17:13:04,29-12-2011
17:13: 7	user3.5: ABC SET TIME17:13:06,29-12-2011
17:13: 9	user3.5: ABC SET TIME17:13:09,29-12-2011

From the above two listings following conclusion are made

1. From PC104 command log at 17:12:12 shows antenna to be positioned at +220:14:34 in azimuth and 17:00:00 in elevation so servo executing the position command.
2. But at instant 17:12:13 "`NEW SRC SPECIFIC TRAK PARA`" are loaded from online and `SETABCT` was issued with time of 17:12:15,29-12-2011. Similarly online sent `SETABCT`to ABC at following instants,

```
17:12:53 user3.5: ABC SET TIME17:12:53,29-12-2011
17:13: 3 user3.5: ABC SET TIME17:13:03,29-12-2011
17:13: 4 user3.5: ABC SET TIME17:13:04,29-12-2011
17:13: 7 user3.5: ABC SET TIME17:13:06,29-12-2011
17:13: 9 user3.5: ABC SET TIME17:13:09,29-12-2011
```

3. *Whenever `SETABCT` issued from control room ABC sends two commands to servo (`ABRT & SET TOD`).*

   Let us consider the instant 17:12:15,

   Dec 29 17:12:13 P (ABORT COMMAND)
   Dec 29 17:13:13 R,17:12:15,29-12-2011 (SET Time of Day command to servo)

   This is happened at all above mentioned `SETABCT` time instants, these are listed below

   Dec 29 17:12:53 P
   De 29 17:12:53 R,17:12:53,29-12-2011
   :
   :
   Dec 29 17:13:01 P
   Dec 29 17:13:03 R,17:13:03,29-12-2011
   :
   :
   Dec 29 17:13:04 P
   Dec 29 17:13:04 R,17:13:04,29-12-2011
   :
   :
   Dec 29 17:13:06 P
   Dec 29 17:13:06 R,17:13:06,29-12-2011
   :
   Dec 29 17:13:07 P
   Dec 29 17:13:09 R,17:13:09,29-12-2011

4. *Whenever ABRT (P) command was came from ABC servo discards the currently running command and trying to HOLD the antenna at that angle. (It is difficult to HOLD the axis at that particular instant after receiving the ABRT because the dynamics of antenna will lead antennato oscillate, to avoid this we are calculating the safe stop position).*

Case 1: This can be explained with help of servo data log file and command log file, Consider the instant 17:13:01 sequence of commands from ABC is,

Dec 29 17:12:54 D,B,17:13:29,+220:15:30,+017:00:00 (TRACK)
Dec 29 17:12:58 $0 1$1 1 (TRACK Complete)
Dec 29 17:13:01 P (ABRT)
Dec 29 17:13:03 R,17:13:03,29-12-2011
Dec 29 17:13:03 D,B,17:13:29,+220:15:30,+017:00:00 (TRACK)

Data Log:

S.No	Time	Current Position	Softstart Position	Target Position	Position Error
10868	17:13:01	17.67700195	16.70963097	17.35718918	-0.99483681
10869	17:13:01	17.64678955	16.68983078	17.35589790	-0.98717117
10870	17:13:01	17.61932373	16.67063141	17.35460854	-0.97615814
10871	17:13:01	17.59185791	16.65203094	17.35331917	-0.96729279
10872	17:13:01	17.56164551	16.63403130	17.35202980	-0.95782661
10873	17:13:01	17.53143311	16.61663055	17.35074043	-0.94501495
10874	17:13:02	17.50122070	16.59983063	17.34945107	-0.93160248
10875	17:13:02	17.47100830	16.58363152	17.34816170	-0.91758919
10876	17:13:02	17.44079590	16.56803131	17.34687233	-0.90297699
10877	17:13:02	17.41333008	16.56803131	17.25329590	-0.90297699
10878	17:13:02	17.38311768	16.55303192	17.25329590	-0.86029816
10879	17:13:02	17.35565186	16.53863144	17.25329590	-0.84448624
10880	17:13:02	17.32818604	16.52363205	17.25329590	-0.83201981
10881	17:13:02	17.30072021	16.50923157	17.25329590	-0.81895447
10882	17:13:02	17.27050781	16.49543190	17.25329590	-0.80528831
10883	17:13:02	17.24304199	16.48223114	17.25329590	-0.78827667
10884	17:13:03	17.21557617	16.46963120	17.25329590	-0.77341080
10885	17:13:03	17.19085693	16.45763206	17.25329590	-0.75794411
10886	17:13:03	17.16339111	16.44623184	17.25329590	-0.74462509
10887	17:13:03	17.13867188	16.43543243	17.25329590	-0.72795868
10888	17:13:03	17.11395264	16.43543243	17.25329590	-0.72795868
10889	17:13:04	17.08648682	16.42523193	17.25232124	-0.68872070
10890	17:13:04	17.06176758	16.41563225	17.25134659	-0.67085457
10891	17:13:04	17.03430176	16.40663147	17.25037384	-0.65513611

From the log file before receiving the ABRT (P) command from ABC, servo is executing the track command of `B,17:13:29,+220:15:30,+017:00:00`. This track should complete at 17:13:29,

But at the instant of 17:13:02 servo got ABRT command at that instant following sequence of operations are happening in servo,

i. Assign the current_angle as a target_angle

ii. Estimate the soft stop angle using equ 3.1

iii. Calculate the find stop position from equ 3.2

iv. Assign final stop position as a target_angle (in this case 17.25329590).

Target angle remains 17.25329590 from line no.10877 to 10888

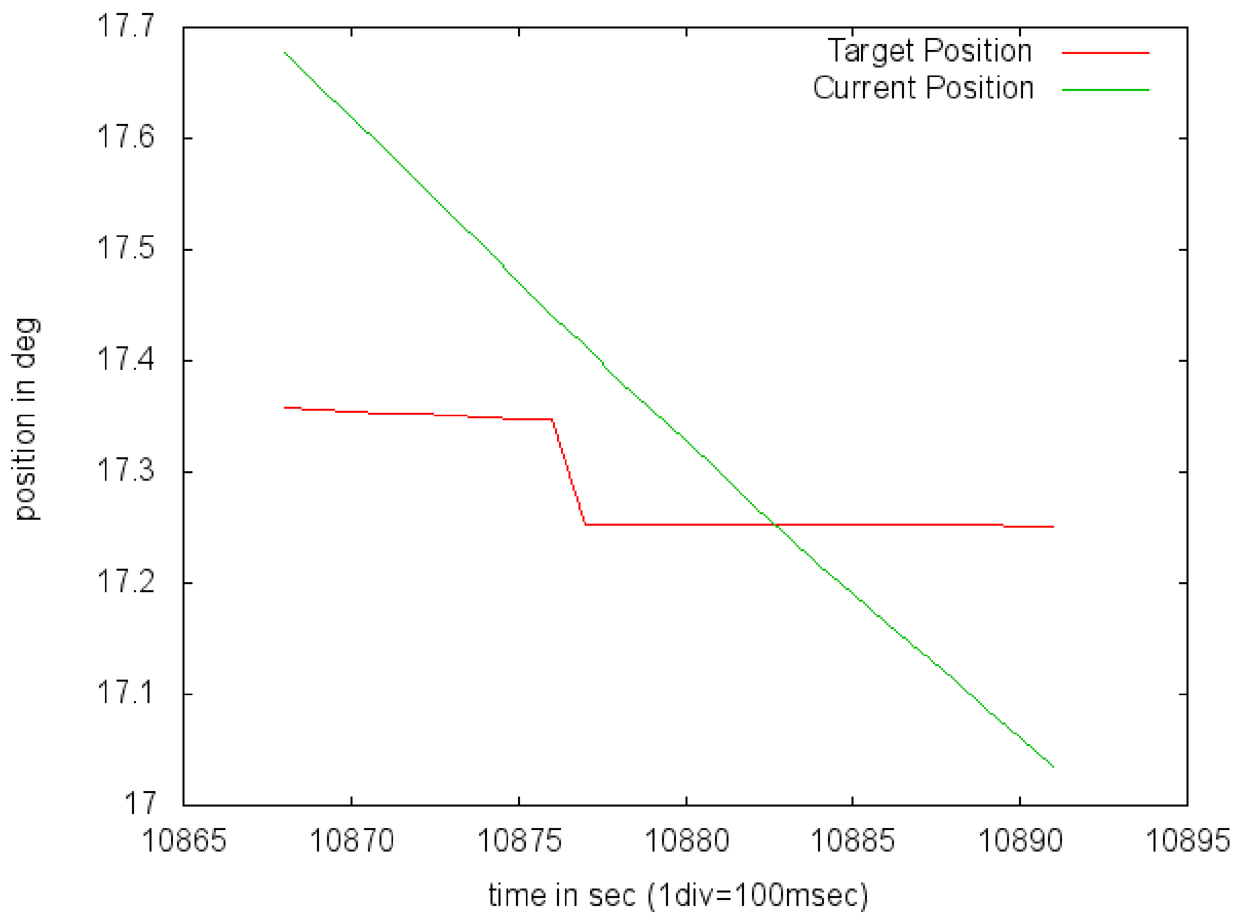

Figure 4-1 Plot1

Once safe stop target reached antenna enter into POSITIONING mode and process the next command in the command box.

Case: 2

Consider the instant 17:13:06 servo received the ABRT command from ABC prior to this instant servo executing the track command of D,B,17:13:29,+220:15:30,+017:00:00.

Dec 29 17:13:04 D,B,17:13:29,+220:15:30,+017:00:00
Dec 29 17:13:06 D,B,17:13:59,+220:17:10,+017:00:00
Dec 29 17:13:06 P
Dec 29 17:13:06 R,17:13:06,29-12-2011
Dec 29 17:13:06 D,B,17:13:29,+220:15:30,+017:00:00

Data log:

S.No	Time	Current Position	Softstart Position	Target Position	Position Error
10904	17:13:05	16.74865723	16.33643341	16.97554588	-0.43144989
10905	17:13:05	16.72943115	16.33343315	16.97559166	-0.41522408
10906	17:13:05	16.71020508	16.33103371	16.97563553	-0.39839745
10907	17:13:05	16.69097900	16.33103371	16.97563553	-0.39839745
10908	17:13:05	16.67175293	16.32923317	16.97567940	-0.36174583
10909	17:13:05	16.65252686	16.32803345	16.97572517	-0.34371948
10910	17:13:05	16.63604736	16.32743263	16.97576904	-0.32509422
10911	17:13:05	16.61956787	16.32743263	16.97581291	-0.30861473
10912	17:13:05	16.60308838	16.32803345	16.97585869	-0.29153442
10913	17:13:05	16.58935547	16.32923317	16.97590256	-0.27385521
10914	17:13:06	16.57287598	16.33103371	16.97594833	-0.25832176
10915	17:13:06	16.55639648	16.33343315	16.97599220	-0.23944283
10916	17:13:06	16.54266357	16.33643341	16.97603607	-0.21996307
10917	17:13:06	16.52893066	16.34003258	16.97608185	-0.20263100
10918	17:13:06	16.51519775	16.34003258	16.97608185	-0.20263100
10919	17:13:06	16.50146484	16.34423256	16.97612572	-0.17096519
10920	17:13:06	16.49047852	16.34903336	16.97616959	-0.15243149
10921	17:13:06	16.47949219	16.49047852	16.49047852	-0.15243149
10922	17:13:06	16.47125244	16.49047852	16.47949219	-0.15243149
10923	17:13:06	16.46575928	16.49047852	16.47949219	0.01922607
10924	17:13:07	16.46026611	16.49047852	16.47949219	0.02471924
10925	17:13:07	16.45751953	16.48987770	16.47949219	0.02961159
10926	17:13:07	16.45751953	16.48900604	16.47949219	0.03148651
10927	17:13:07	16.45751953	16.48799706	16.47949219	0.03047752
10928	17:13:07	16.45477295	16.48799706	16.47949219	0.03047752

The below fig. 4-2 shows plot for the above data,

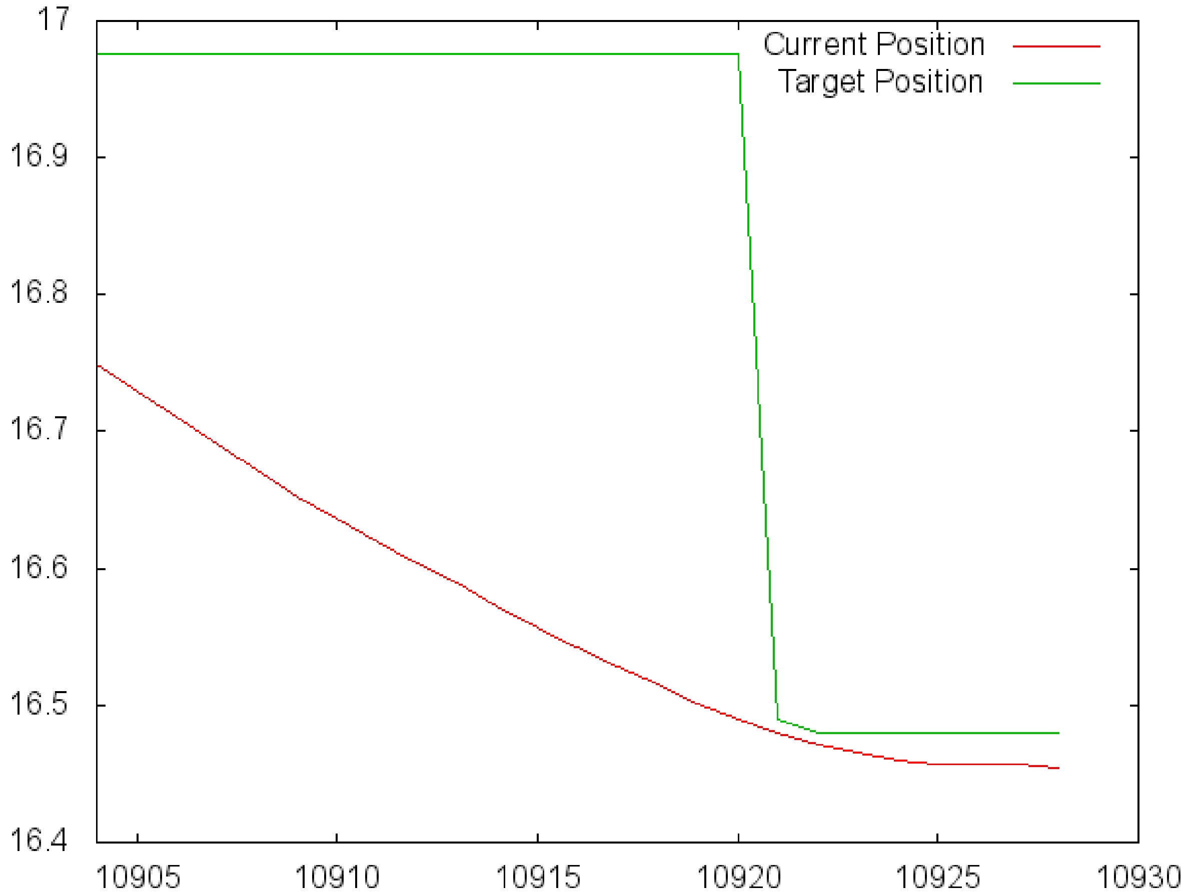

Figure 4-2 Plot 2

From the plot from 10905 to 10920 antenna was tracking towards the target, at 10920ABRT command to be executed but 10920 current_angle (16.49047852) is less than the down soft limit (16.5), so antenna controller initiates the axis_off functions and waits for the drives disabled and applied brakes feedback. During axis_off time delay () antenna in POSITIONING state and takes the ABRT command and calculate safe stop target from the current_angle.

Current Angle at ABRT to execute = 16.49047852

Estimated soft stop angle = 16.47949219

With this antenna moves towards target and once axis_off delay was over antenna controller puts the system into STRLSDBKD state.

4.1 Analysis during Positioning

There is chance of soft limits getting hit of the EL axis by giving the 1º to 3º step command close to the limit region. The following plot shows the step command of 3º from 20 º to 17º given because of current position goes below the soft limit (16.5) antenna controller initiates the axis_off function by assigning the target to current angle i.e.(new target = 16.49047852) and disables the amplifiers and applies the brakes. Finally antenna controller enters into STRLSDBKD state.

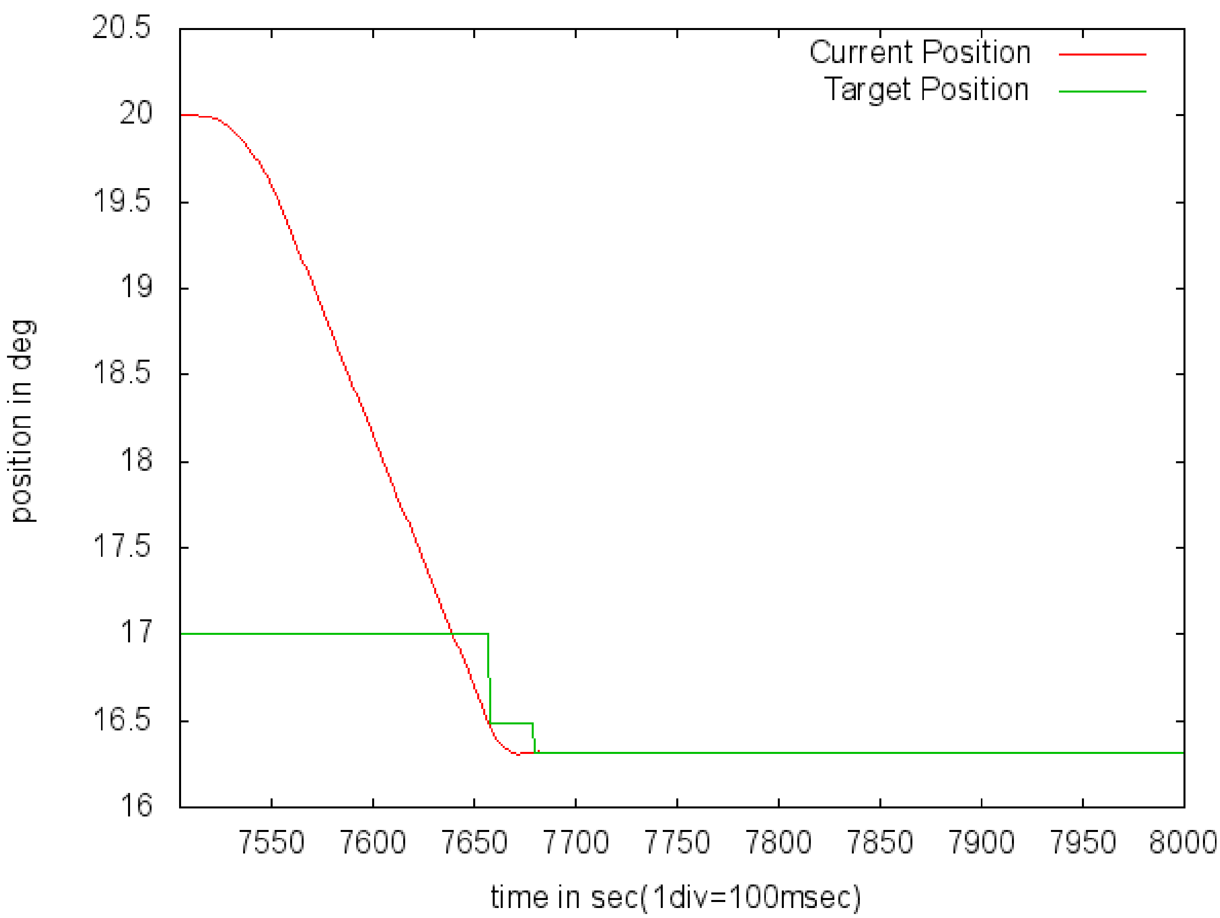

Figure 4-3 Step Response near limit region

4.1 Step response of all antennas from 20° to 17° command from CEB

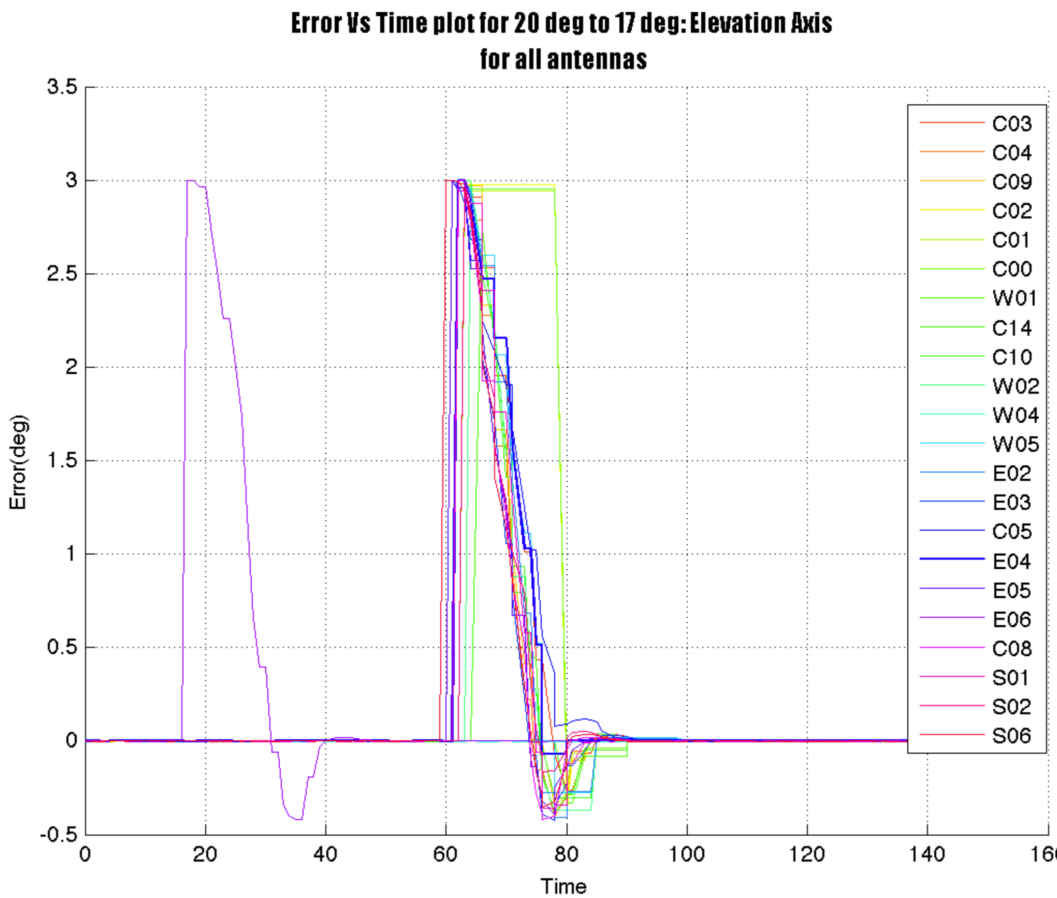

Figure 4-4 Step Response for 30 antennas

5. Conclusion

Based on the experiment conducted in W02, E04 and all 30 antennas, the following conclusions are arrived,

In EL axis, when antenna in tracking, servo target angle goes below the servo software limits, because of repetitive SETABCT command received from the ABC. The reason for generating target angle below the software limit is to safely stop the antenna with gradual decrease in speed. In order to avoid these software limit crossing problems the following suggestions are given by Servo Group Members and SMEC Committee,

a. For 8086 and PC104 based SSC antennas control room telescope operators are instructed not to issue SETABCT command near limit region in EL axis.
b. In PC104 servo software this problem can be addressed by implementing the following, condition, target angle is less than safe stop angle, assign software low limit as target angle.

Appendix

Percentages overshoot Vs difference in angle for antenna W02 as tracking with HHT Performed on 22 Dec 2011

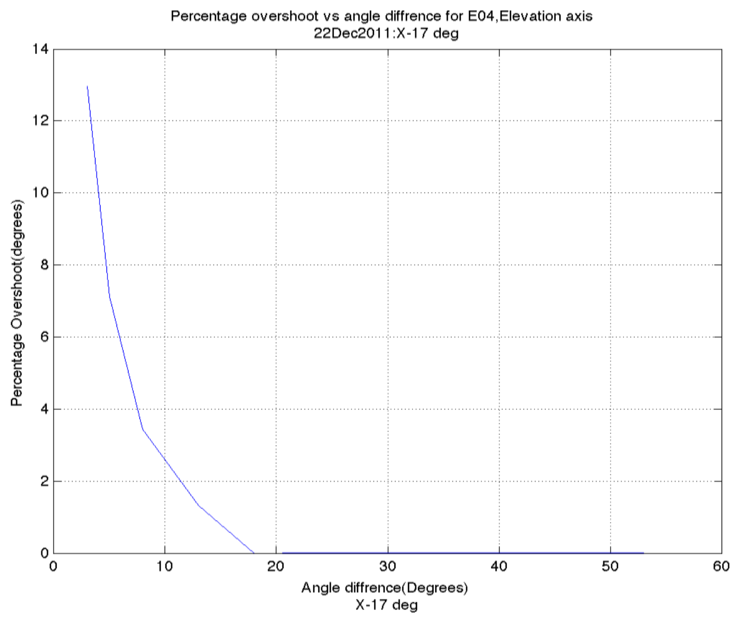

Figure A-1 Plot Percentage Overshoot vs Angle Difference

Percentage overshoot Vs difference in angle for antenna W02 as tracking with HHT performed on 20 Dec 2011

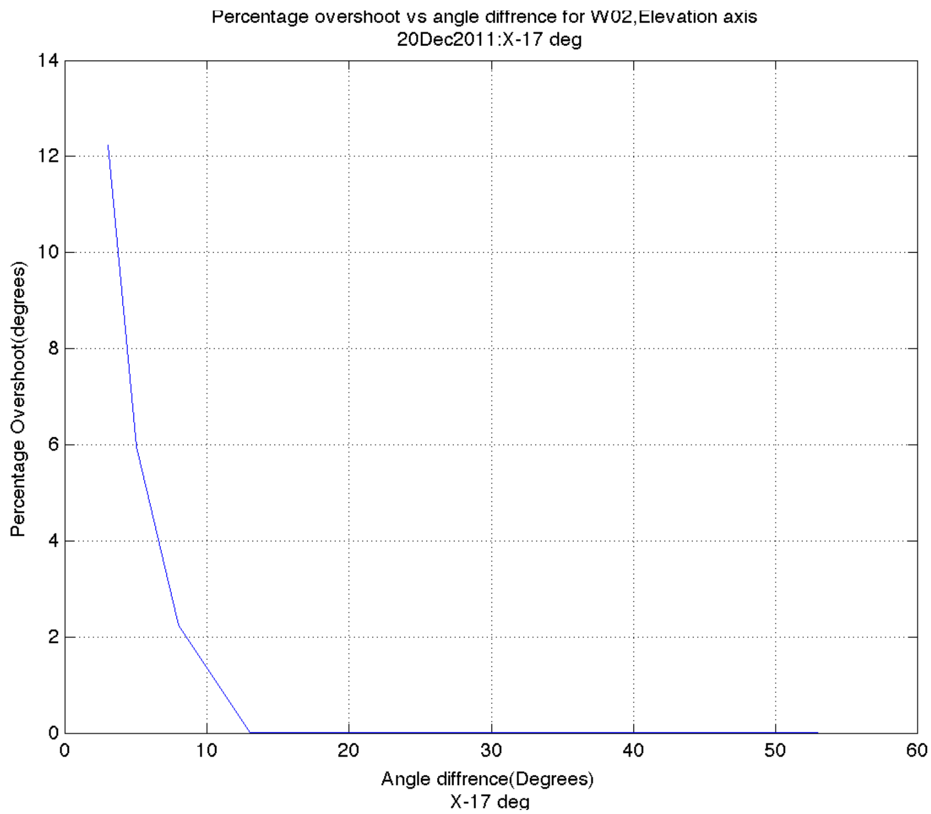

Figure A-2 Plot Percentage Overshoot vs Angle Difference