IMT 504 Chopper Performance Test during cold FM-ILT/IST

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Req. IMT 504 Chopper Performance Test during cold FM-ILT/IST

IMT 504 - A. History

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1.0	August 2, 2007	J.Bouwman (MPIA), U. Klaas (MPIA) J. Schreiber (MPIA), H. Dannerbauer (MPIA) M. Nielbock (MPIA)	
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IMT 504 - B. Summary

In order to achieve fast transition times and high plateau position accuracy with small overshoots an active control of the chopper drive is needed. The implementation comprises a PID loop, a velocity loop, a current feedback loop and a filter for suppression of axial resonances. The parameters of these loops must be tuned for an optimal performance of the chopper. The steps and results of the optimization of the chopper controller parameters are described in document PICC-MA-TR-024. Here we describe the results of the ILT/IST chopper performance reference test, assessing the quality of the current chopper control parameter set by characterizing the chopper transition behaviour and determining the duty cycle depending on the chopper frequency.

To test the chopper performance, the following considerations should be taken into account: a) The chopper mirror should spend a high percentage of a chopper cycle and with high accuracy in a defined plateau position allowing measurements and, b) transition times should be minimal. The plateau accuracy around the commanded chopper angle is ±1 arcmin. For on-sky measurements a duty cycle of 80% in square wave mode with maximum peak-to-peak throw (±3') and for a chopping frequency of 10 Hz is required, i.e. a plateau time of 40 ms and a transition time of 10 ms. For measurements on the internal calibration sources with more than the double elongation angle a duty cycle of 70% in square wave mode and for a frequency of 5 Hz is required, i.e. a plateau time of 70 ms and a transition time of 30 ms. Since transition time and plateau time can be individually commanded and the former one can be kept constant while extending the plateau time, for lower chopping frequencies the duty cycle will be better than the specifications above.

As we will discuss in the following sections, the chopper can be operated in a stable way, resulting in a good plateau stability, independent of chopping frequency. The chopper controller parameters used for the IST tests do not meet the requirements concerning duty cycle and transition time. However, during ILT3 a better controller parameter set has been determined, which results in much faster transition times. With these parameters the specifications for ±8 degree chopping are met, while for ±4 degree chopping the transition times are close to specifications.

IMT 504 - C. Data Reference Sheet

Ref	Date	Archive filename
PACS Calibration Document (PCD req. 2.3.1)	05-Jan-2007	PACS-MA-GS-001 Draft 8 (RD1)
DEC/MEC User Manual	05-Jun-2007	PACS-CL-SR-002 (RD2) Issue 4.3 DEC/MEC controller description
Investigation of PACS Chopper (FM1 Model) Duty cycle of waveforms from FM ILT tests PCD req. 2.3.2 control loop optimization		PICC-MA-TR-024
FM-ILT/IST chopper performance test measurements	10-Apr-2007	FILT_IST_20070410_504_Chopper_Performance_35.tm

IMT 504 - D. Test Description

To assess the chopper performance, chopping has been performed for a ±4 degree chop throw, followed by a chop throw of ±8 degrees. This pattern has been repeated 3 times for different chopping frequencies of 1, 2 and 4 Hz, respectively. The used chopper controller parameters are listed in Table 1. These parameters represent the best chopper settings determined after ILT2. For a general overview on the subject and the chopper controller parameters, and optimization see RD1 and RD2. The HK parameters used for this report where sampled with 256 Hz and are listed in Table 2. To characterize the chopper performance, we determined the transition time from the positive to the negative plateaux and vice-versa. The transition time is defined as the time difference between the moment when the chopper is moving out of the allowed corridor around one deflection angle, and settling into the specified corridor around the plateaux of the opposite deflection. For a nominal transition time of 10 ms for a ±4 degree chop throw, the corresponding plateaux times are 490, 240 and 115 ms for a 1, 2 and 4 Hz chopping frequency, respectively. For a nominal transition time of 30 ms for a ±8 degree chop throw, the corresponding plateaux times are 470, 220 and 95 ms for a 1, 2 and 4 Hz chopping frequency, respectively.

Table 1: Chopper controller parameters used during IST test (nominal DEC/MEC)

Controller parameter	Value Dec.	Value Hex.
Kp	590000	900B0
Ki	36200000	2285E40
Kd	380	17C
Kf	2385	951
Rate	550	226
AccumLimit	25000	61A8
OutputLimit	27100	69DC
Scaling		
ErrorLimit		
PosOffset	-1195	FFFFFFFB55
KiCurr	340000	53020
PosMultiplier		
SPMultiplier		
OutFactor	543	0000021F
PrevOutFactor	972	00003CC
PrevPrevOutFactor	543	0000021F
NotchPrevOutFactor	1139	00000473
NotchPrevPrevOutFactor	251	000000FB
Inductance	148	00000094
Resistance	14650	0000393A
ControlLoopGain	1000	000003E8

Table 2: Diagnostic housekeeping data checked during the IST test, at a sampling frequency of 256 Hz. The first colum lists the diagnostic housekeeping id number, the second column the name of the housekeeping parameters as it appears in the DECMEC documentation.

DIAG HK LIST ID	Parameter Name
209	DM_CHOP_CTRL_ST
244	DM_CHOP_CUR_POS
245	DM_CHOP_SETPOIN
246	DM_CHOP_TARGET
247	DM_CHOP_PID_ERR
248	DM_CHOP_PID_ACC
249	DM_CHOP_MAX_DIT
258	DM_CHOP_OUTPUT
407	DM_CHOPPER_TEMP
557	DM_CHOP_VA
561	DM_CHOP_IA
565	DM_CHOP_VB

IMT 504 - E. Results

To characterize the chopper performance we have checked the diagnostic housekeeping data listed in Table 2. We found no anomalies for any of the listed parameters. Therefore, in the following analysis we will focuss on the DM_CHOP_CUR_POS and DM_CHOP_OUTPUT data. Figure 1 shows an overview of the chopper position readout and output current of the entire chopper performance test. As one can see in this figure, the test is divided into three blocks, corresponding to the different chopping frequencies of 1, 2 and 4 Hz, respectively. Within each block, we first chopped 20 times between ±4 degrees, followed by a series of 20 chops between ±8 degrees. This sequence is repeated twice, after which the chopper is commanded to zero. Looking at the output current, one can see that for the smaller angle transitions, higher acceleration and brake current peaks are required than for the larger angle transitions due to the faster stimulus transition time, which reverses the angle pattern. The narrow high current peaks at the end of each block is the braking peak towards zero position, which is due to the chopper being stopped halfway through the transition at the point where the chopper normaly reaches the highest angular velocity.

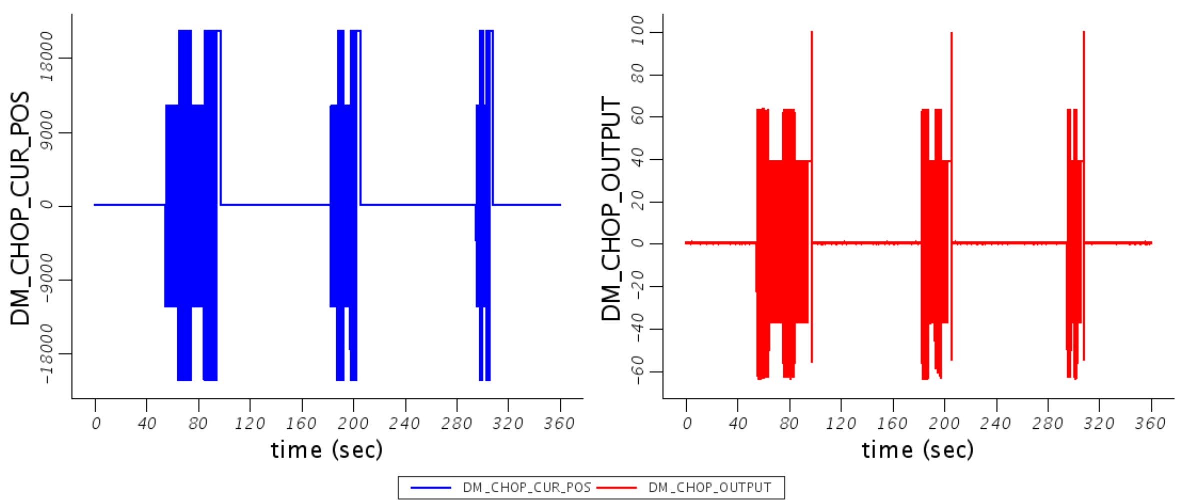

Figure 1: Overview of commanded Chopper position readout (left figure) and output current (right figure) of the ILT/IST chopper performace test.

Figures 2 and 3 show the overview of the chopping tests between ±4 degrees for the different chopping frequencies. From these figures it is clear that a stable chopping pattern can be obtained independent of the chopping frequency. A similar result has been obtained for chopping between the calibration sources at ±8 degrees. A more detailed view of the transition into the chopper plateau can be seen in Figures 4 to 7. Figures 4 and 5 show the transition from the negative to positive chopper plateaux, and vice-versa, for the ±4 degree chopping tests, while Figures 6 and 7 show the chopper transition for the ±8 degree chopping tests. The following can be noticed from these figures: First, the chopper transition does not depend on the chopping frequency. For the investigated frequency range, the behaviour of the chopper transition remains the same, meaning that the transition time of about 40 ms remains constant with changing chopping frequency. A similar behaviour can be observed for the chopping tests between ±8 degrees, for which the transition from the negative to positive chopper plateaux, and vice-versa, can be seen in Figures 6 and 7. The observed transition time is about 70 ms. Secondly, one notices that, though similar, the transition into the positive and negative plateau is not completely identical. We shall come back to this point in the discussion.

The behaviour of the output current during the transition from one plateau into the next can be seen in Figures 8 and 9. One can clearly see the acceleration and deceleration spike in the current, pulling the chopper out of the positive plateau and stopping its movement when entering the negative plateau. Comparing the figures, one can clearly see the difference in the required current for the chopping between ±4 degrees compared to the ±8 degrees chop, where the former requires an amplitude of the acceleration/deceleration spikes of about 60 mA, while for the latter the amplitude remains below an absolute value of 37 mA, which is the static current required to maintain an 8 degrees chopping position.

We also checked the stability of the chopper on the plateaux. For this, we determined the standard deviation and made a FFT analysis of the position readout of the period when the chopper was positioned on a plateau. The results of this can be seen in Figures 10 through 13. These analyses did not show any significant disturbances of the chopper position, though one can see that there is an apparent increase in noise with increasing chopping frequency. The reason for this are the initial ascillations with larger amplitude which weight more strongly for the shorter plateau times. This is also reflected in the FFT amplitudes which are higher at low frequencies for the faster chopping. However, it is important to realize that for all tests the chopper is well within the specified limits of about 50 and 100 readout units around the 4 and 8 degree plateaux, respectively. The maximum stability, where the position is varying just a few readout units, far better than required, takes much longer time to acquire than the transition time, and can only be reached for the lowest chopping frequency.

Finally, we checked the temperature behaviour of the chopper. Figure 14 shows the chopper temperature with time. Clearly visible in this figure are three maxima, corresponding to the three measurements at different chopper frequencies as seen in Figure 1. Note that there is an apparent time shift between the temperature peaks and the start of a chopping sequence at a given frequency as seen in Figure 1. This, however, reflect the low rate of 20 s at which the temperature data is being updated. We can observe a maximum temperature increase of only 0.03 K during chopping. This small temperature increase is not anomalous and points towards a expected heat dissipation during chopping (see also the test report on the thermal behaviour tests during FM-ILT (ICC-ME-TR-002)).

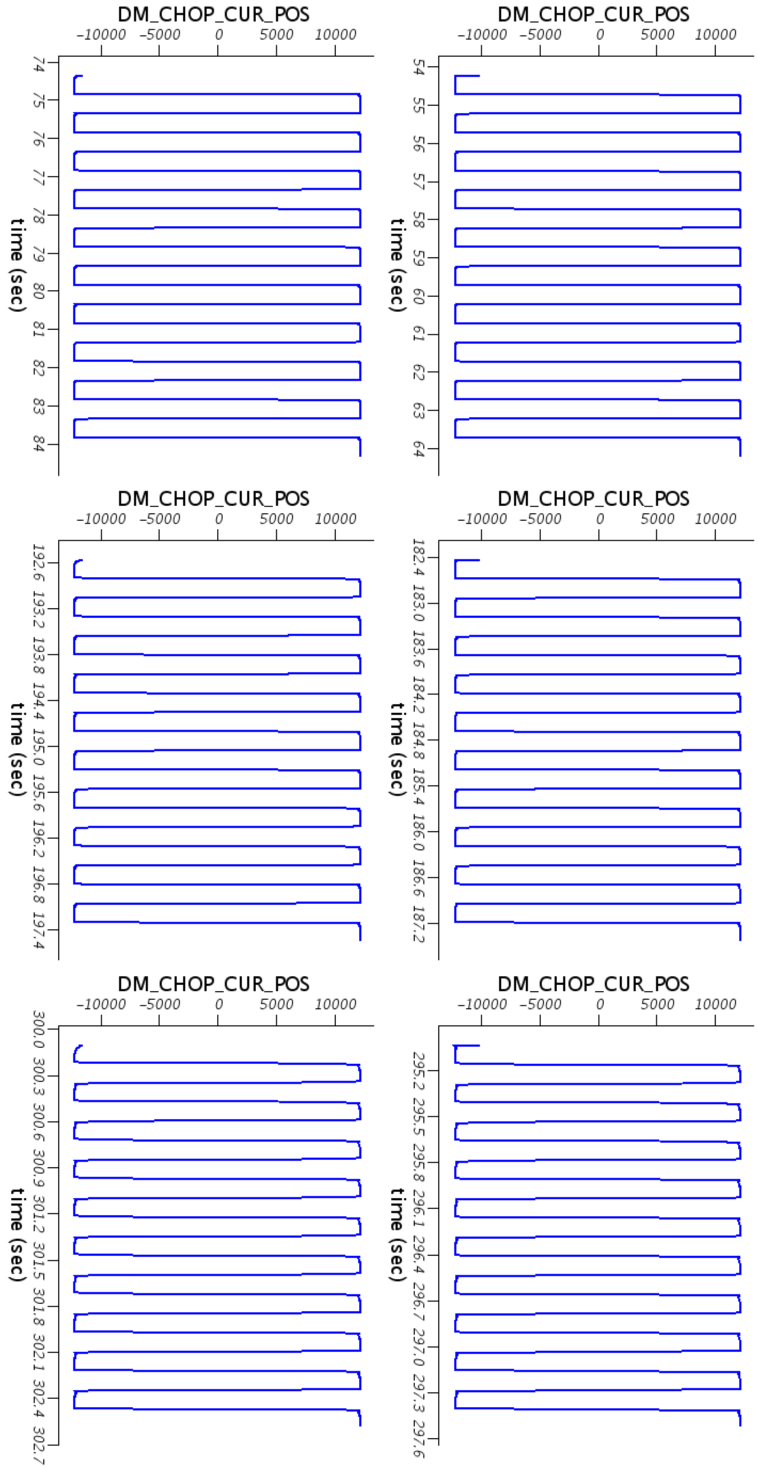

Figure 2: Overview of commanded Chopper position readout for the 4 degree chop. The panels show, from left to right, the chopper position readout for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence (see also Fig. 1), at the same chopping frequency.

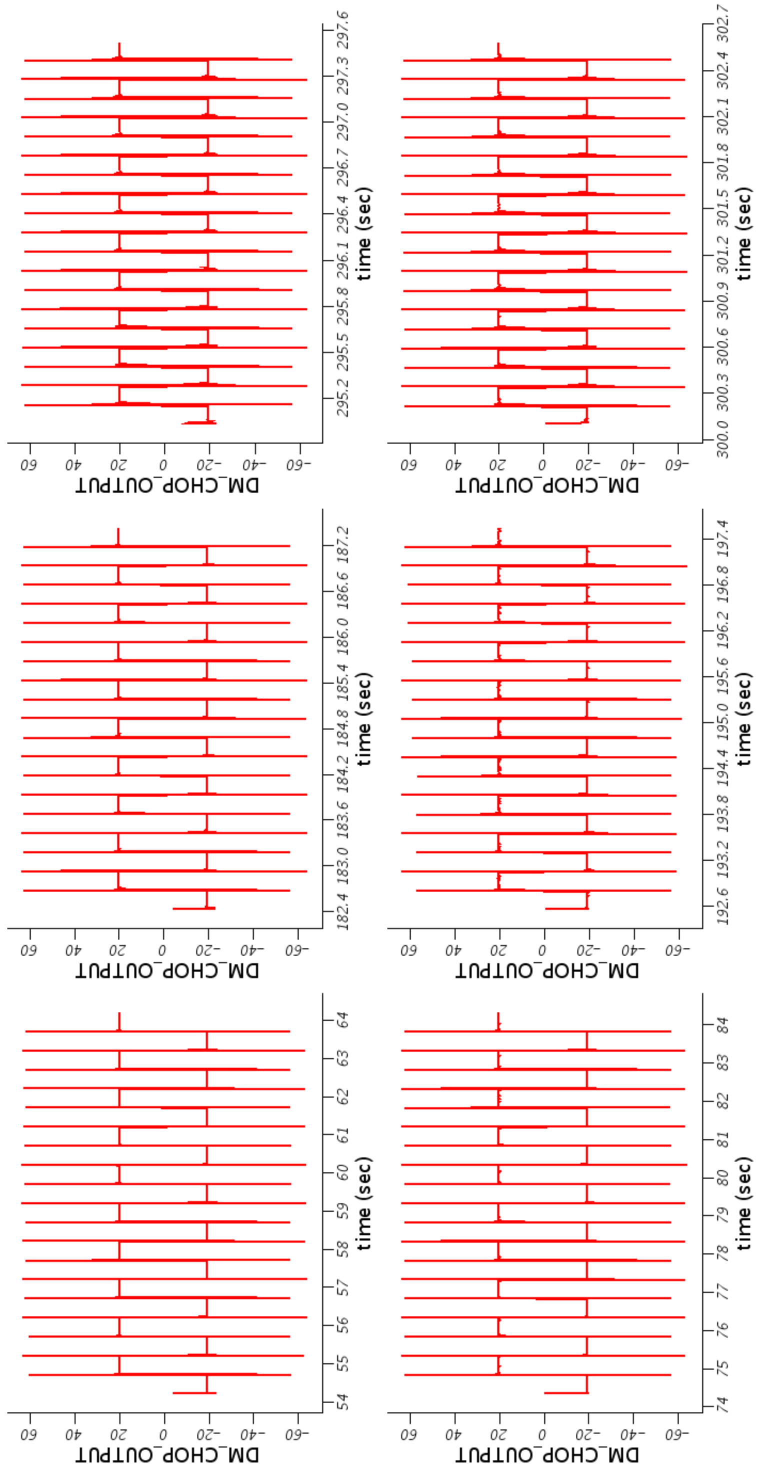

Figure 3: Overview of commanded chopper output current for the 4 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence (see also Fig. 1), at the same chopping frequency.

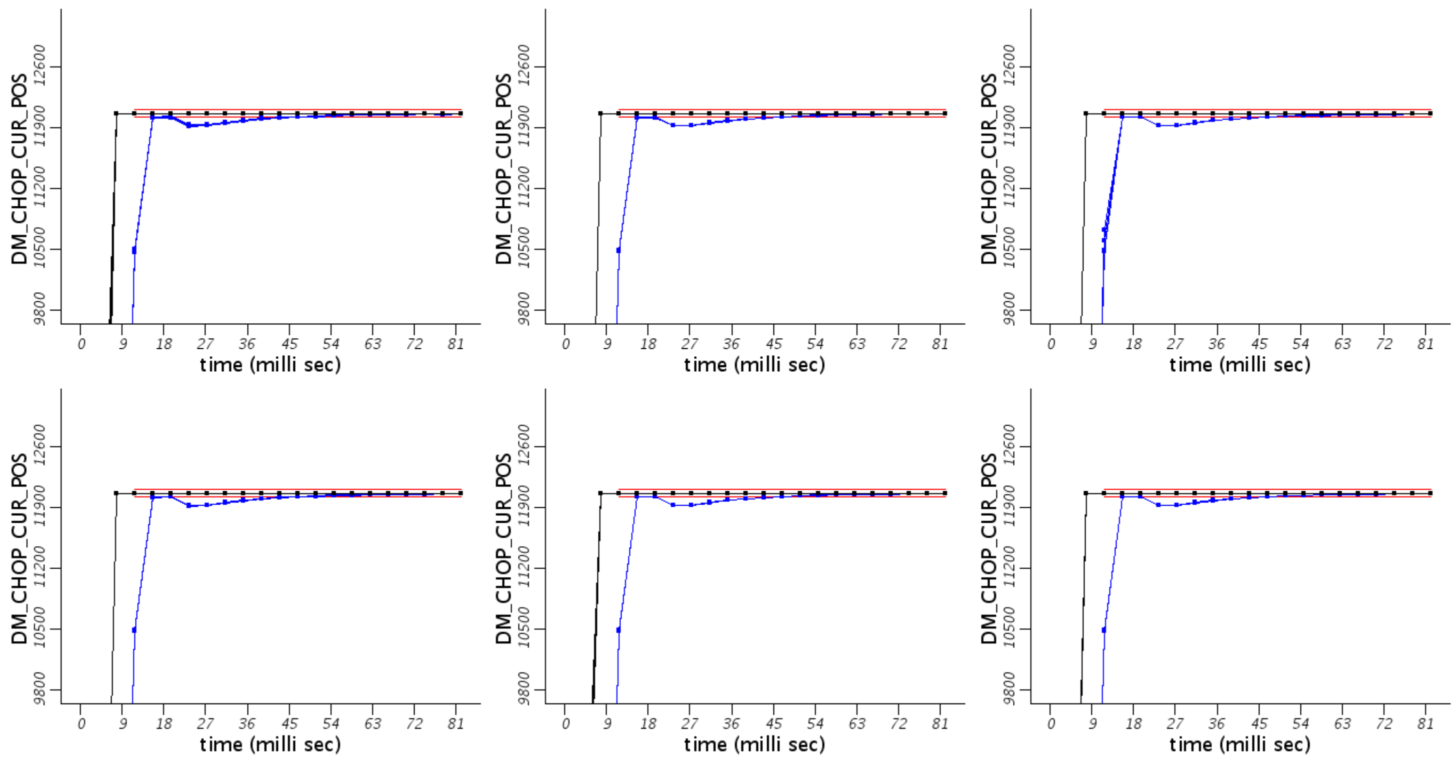

Figure 4: Transition from negative to positive chopper plateaux for a ±4 degree chop. The panels show, from left to right, the position sensor read-out signal for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. The blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits.

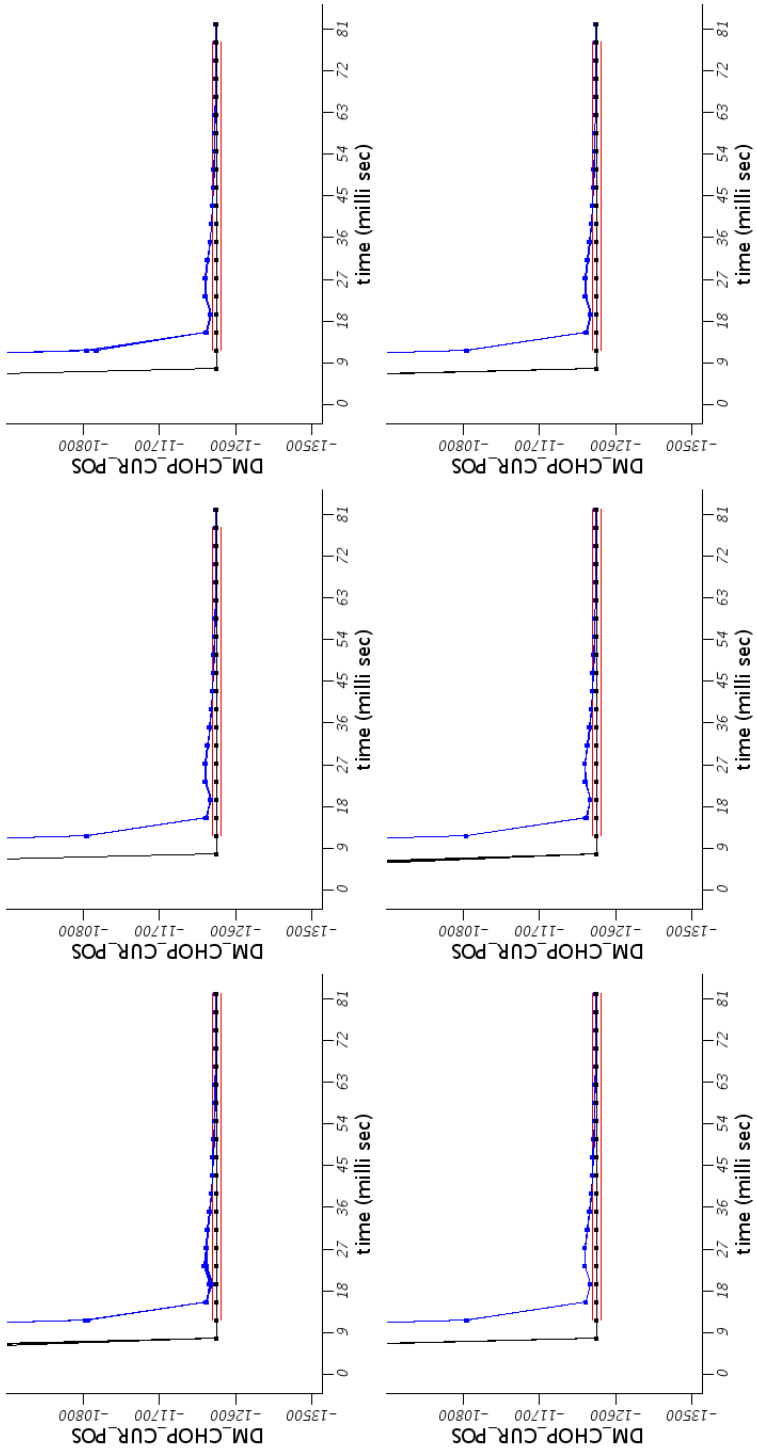

Figure 5: Transition from positive to negative chopper plateaux for a ±4 degree chop. The panels show, from left to right, the read-out signal of the position sensor for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. The blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits.

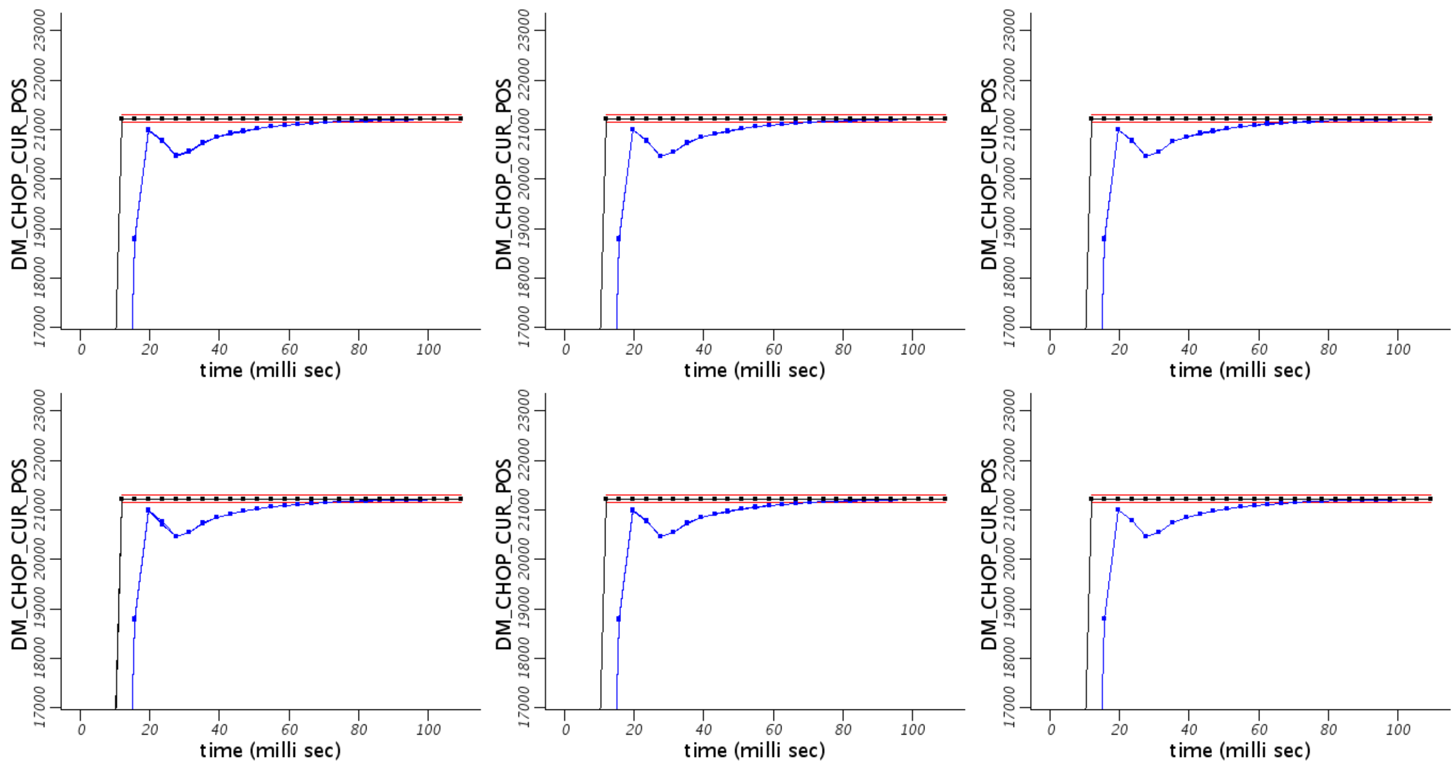

Figure 6: Transition from negative to positive chopper plateaux for a ±8 degree chop. The panels show, from left to right, the read-out signal of the position sensor for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. The blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits.

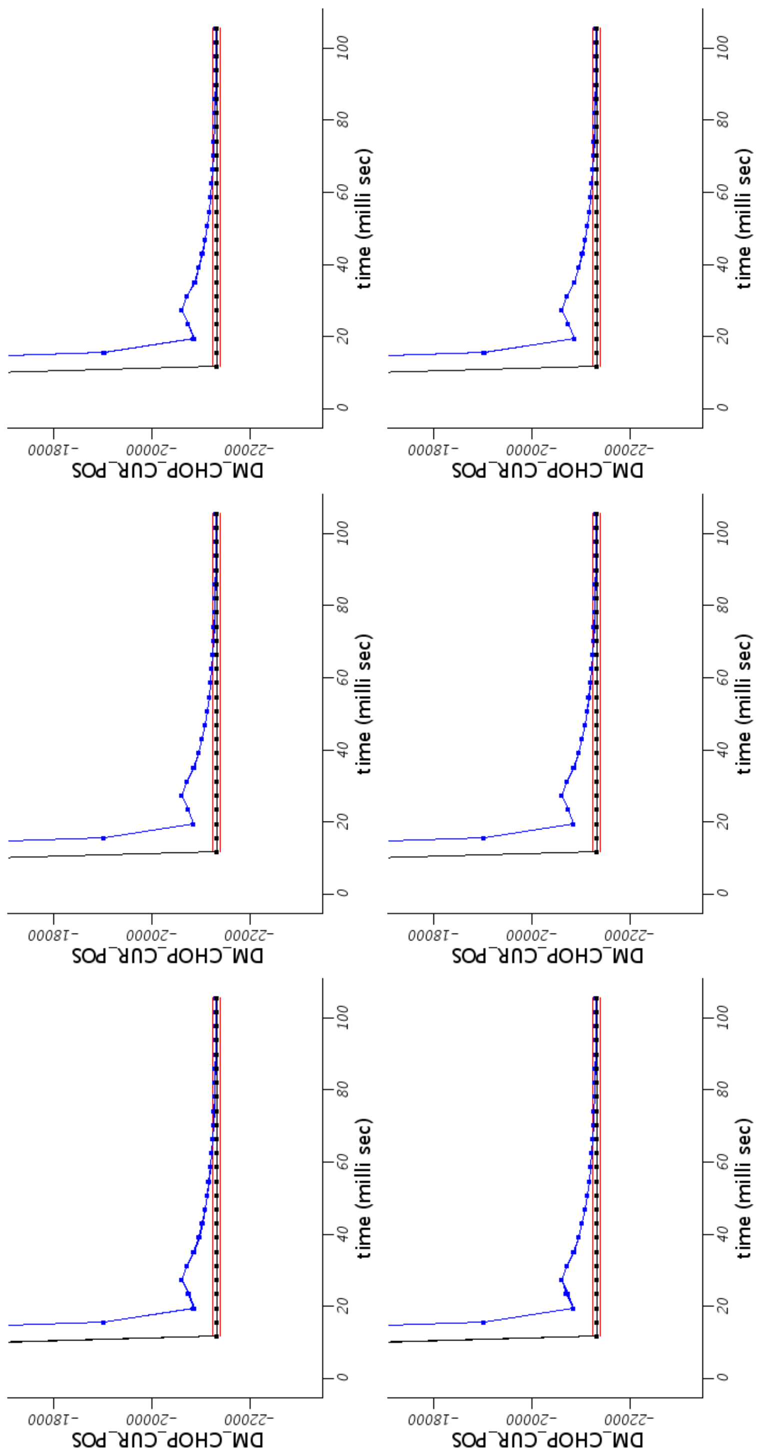

Figure 7: Transition from positive to negative chopper plateaux for a ±8 degree chop. The panels show, from left to right, the chopper position for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. The blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits.

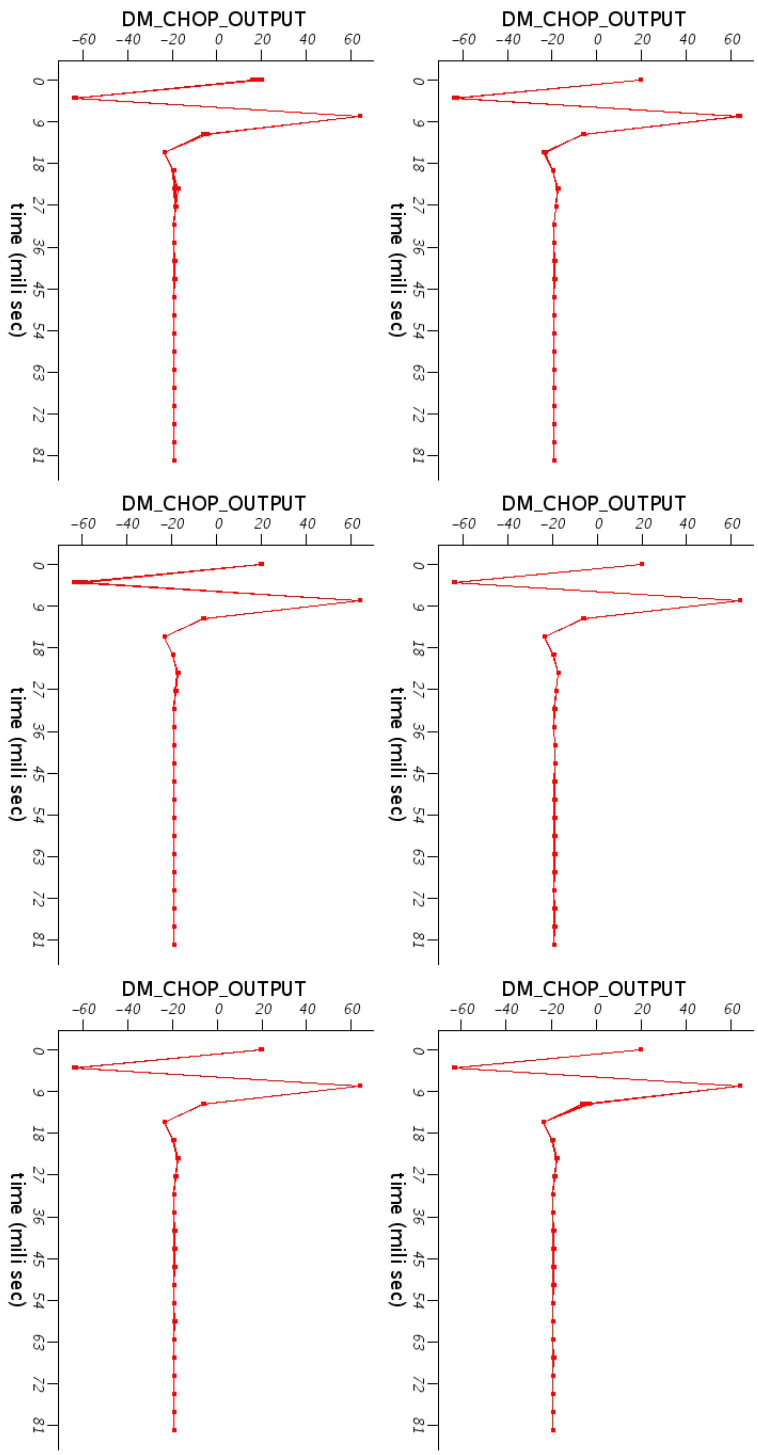

Figure 8: Behaviour of the output current (in mA) in the transition from positive to negative chopper plateaux for a ±4 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency.

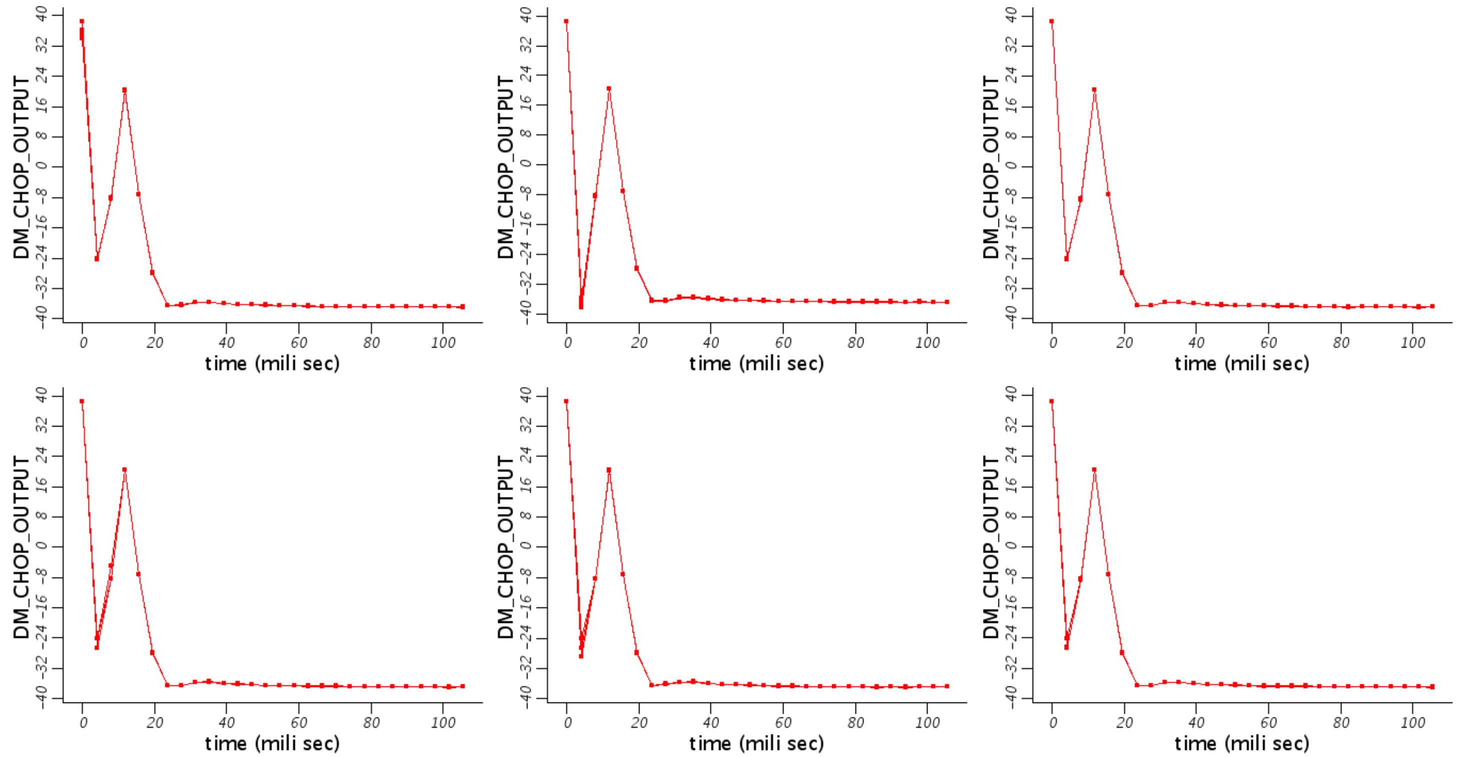

Figure 9: Behaviour of the output current (in mA) in the transition from positive to negative chopper plateaux for a ±8 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency.

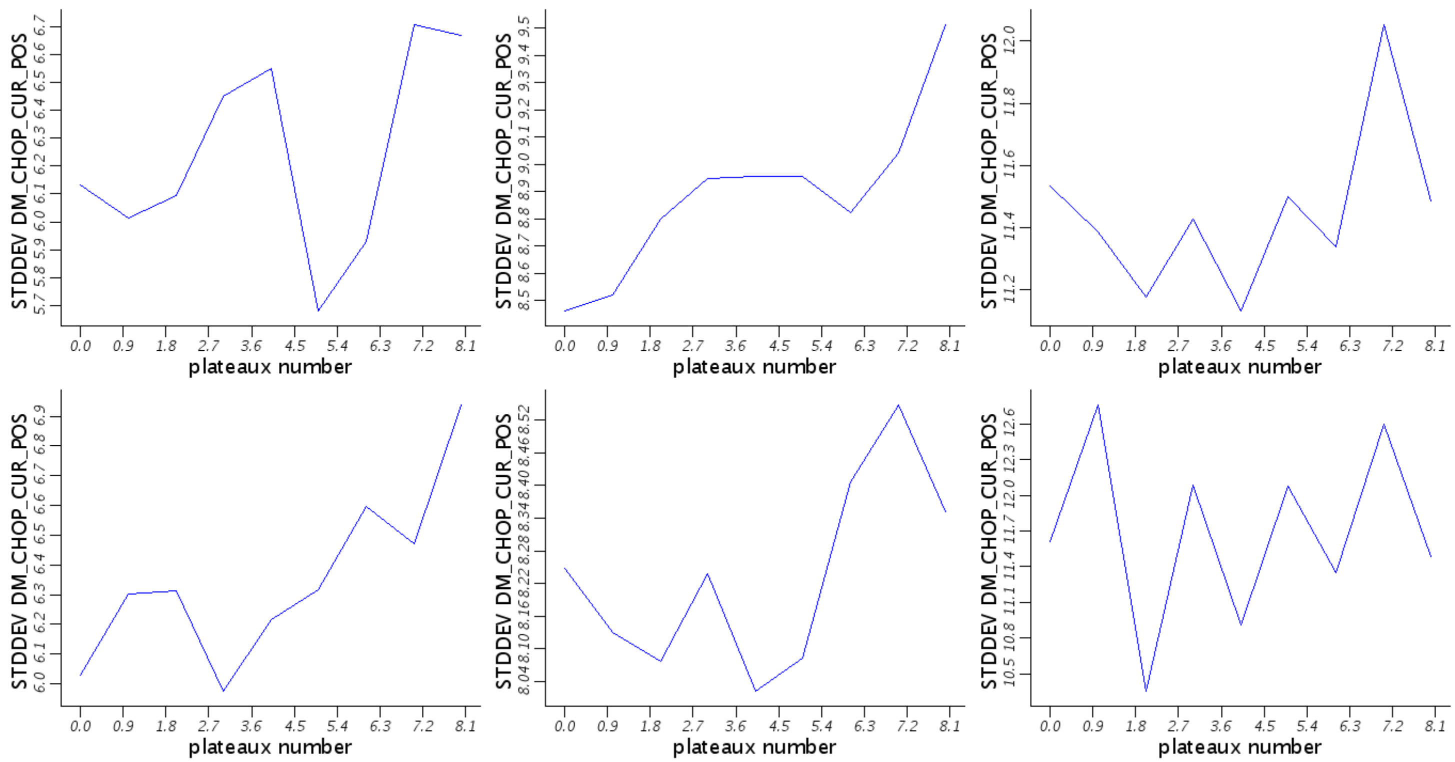

Figure 10: Standard deviation of the chopper position readout on the negative plateaux for a ±4 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency.

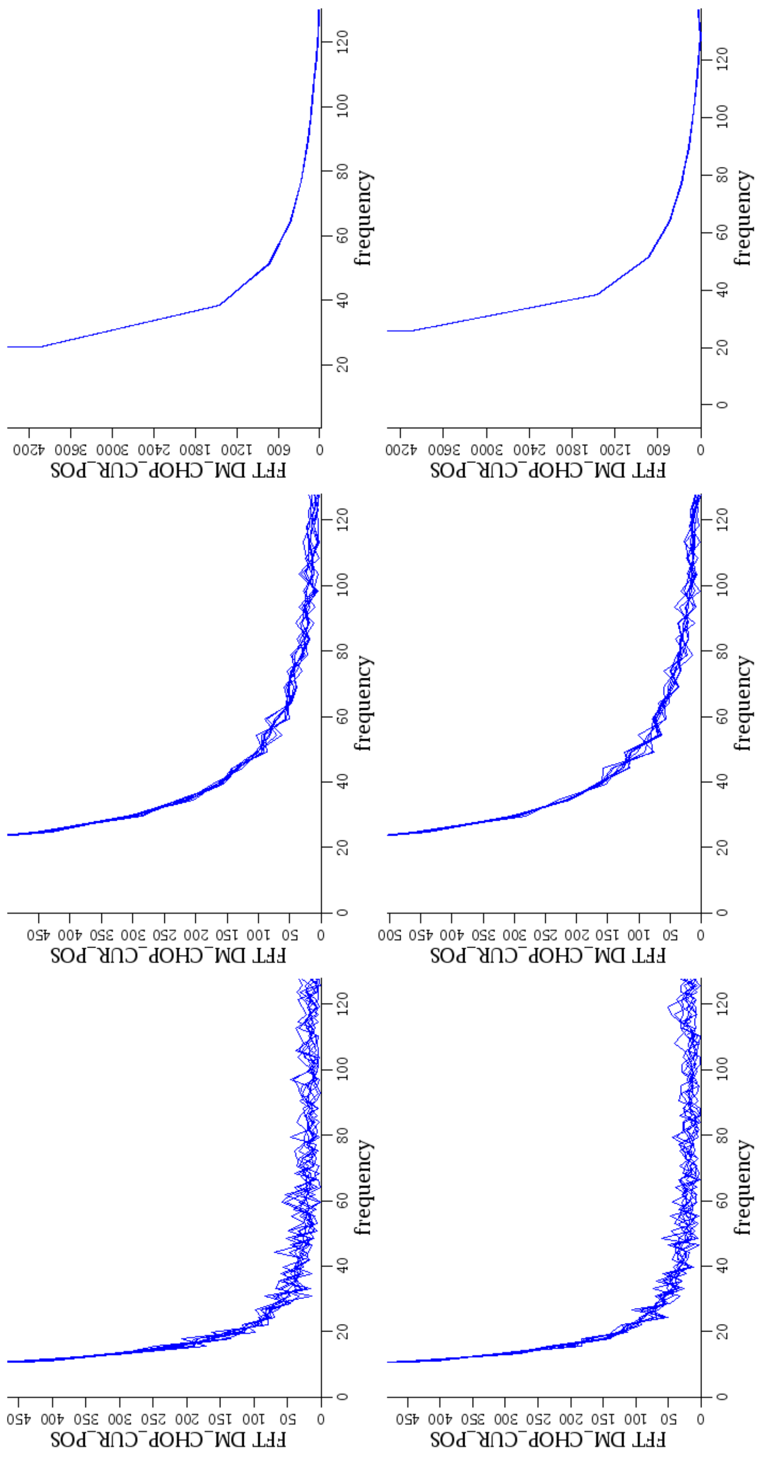

Figure 11: FFT of the chopper position readout of the negative plateaux for a ±4 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. Due to the sampling frequency of 256 Hz, the FFT analysis is restricted to 128 Hz.

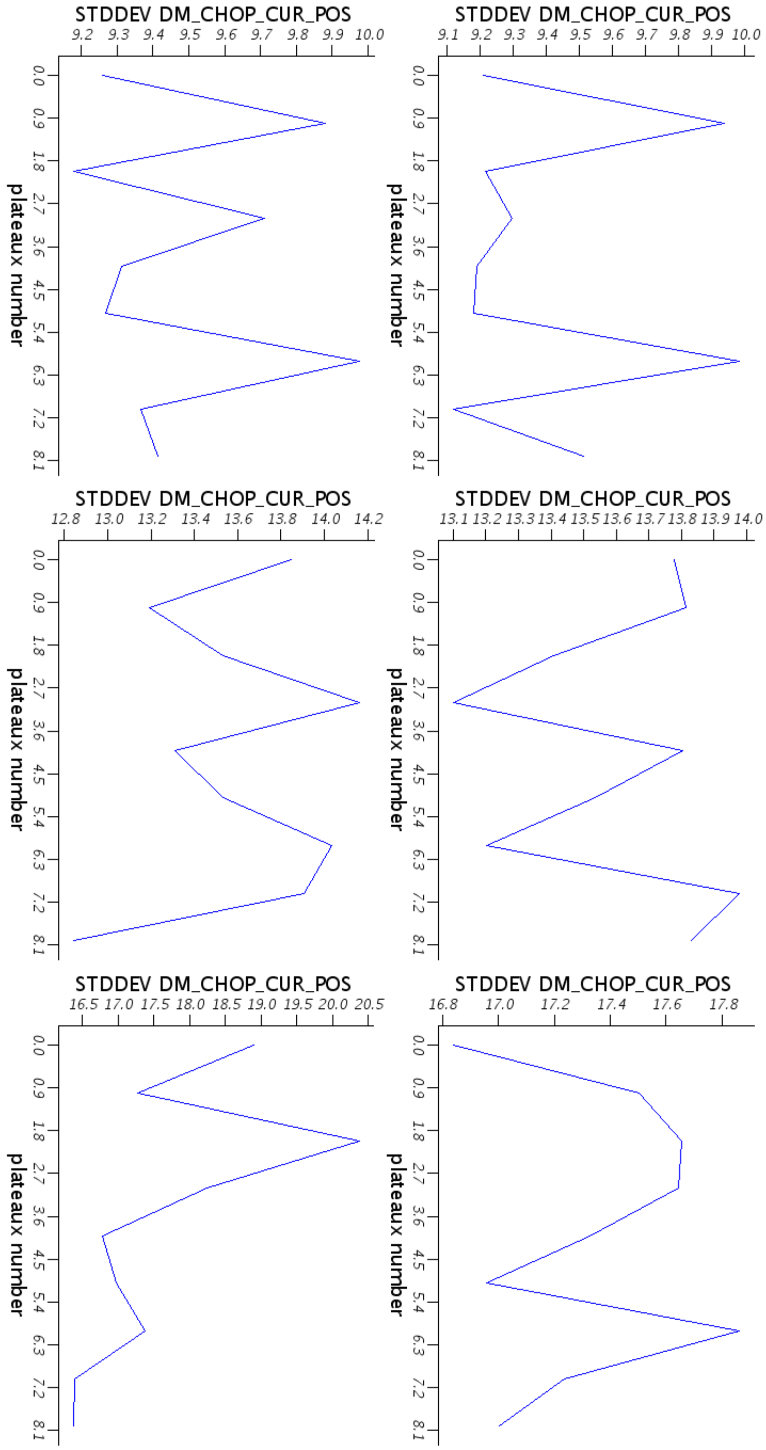

Figure 12: Standard deviation of the chopper position readout on the negative plateaux for a ±8 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency.

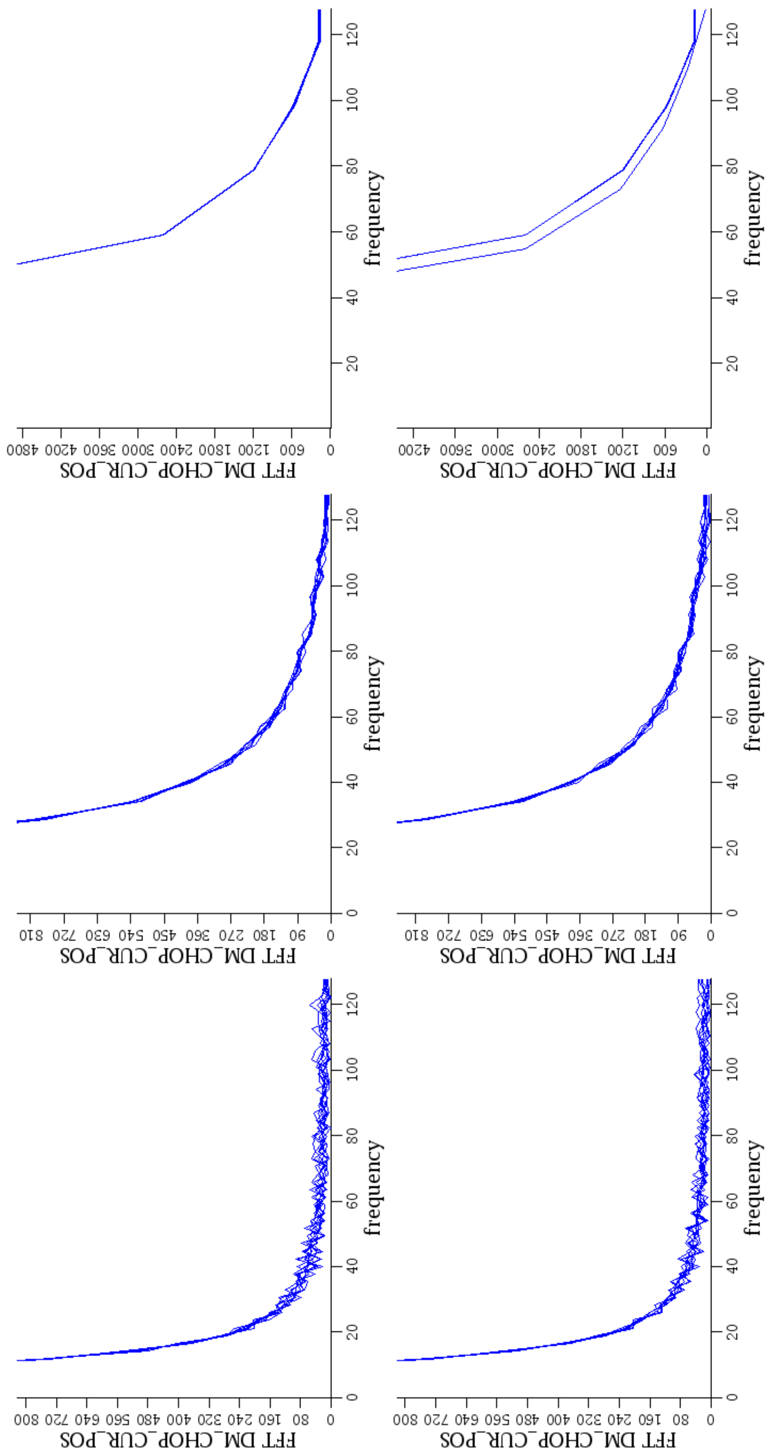

Figure 13: FFT of the chopper position readout on the negative plateaux for a ±8 degree chop. The panels show, from left to right, the chopper output for chopping at 1, 2, and 4 Hz, respectively. The top and bottom panels show the first and second chopping sequence at the same chopping frequency. Due to the sampling frequency of 256 Hz, the FFT analysis is restricted to 128 Hz.

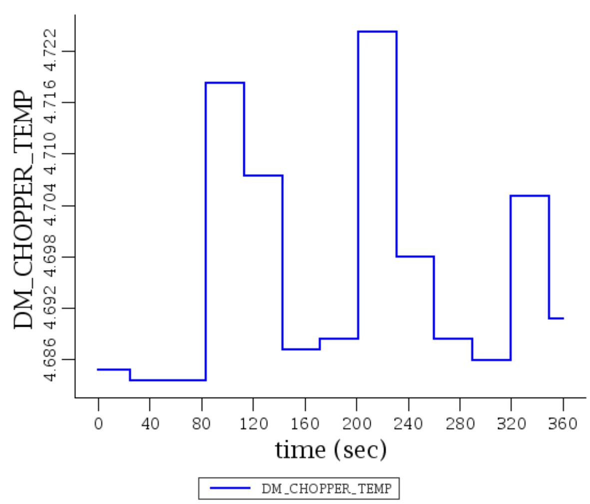

Figure 14: Bahaviour of the measured chopper temperature readout (in K) during the ILT/IST chopper performace test.

IMT 504 - F. Conclusions

In conclusion we can state that a stable chopping pattern can be obtained, for both on-target chopping and chopping between the calibration sources. This is independent of the chopping frequency up to the maximum tested frequency of 4 Hz. With the chopper control parameter set used during this IST test, transition times of around 40 ms for chopping bewteen ±4 degrees, and 70 ms for chopping between ±4 and ±8 degrees, respectively, could be obtained. This is above the specifications of 10 ms and 30 ms transition time, respectively. Figure 15 shows the results for the transition time and the resulting duty cycle. Note that the results for the asymmetric chopping pattern between +4 and -8 degrees fall in between the results of the symmetric chopping between ±4 and ±8 degrees. This suggests that the transition time depends on the total angular move, rather than the start and end position.

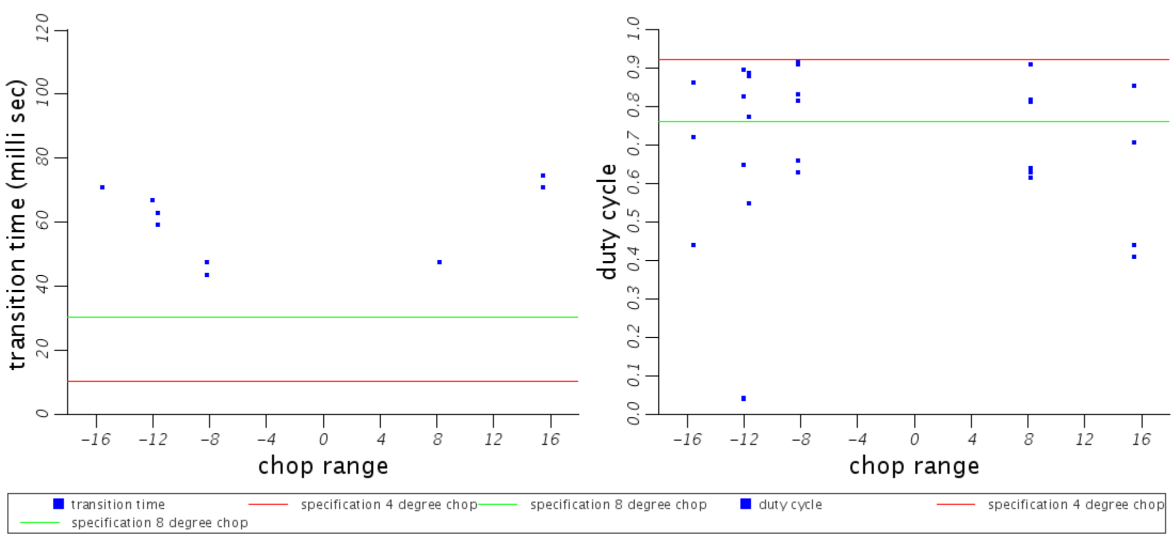

Figure 15: Summary of the chopper transition times and duty cycles. The left panel shows the measured transition times (blue dots), the right panel the corresponding duty cycle. The x-axis represends the peak-topeak angle. Hence, -16 and 16 correspond to a chop from 8 to -8 degrees and from -8 to 8 degrees, respectively. Similarly, -8 and 8 correspond to a chop from 4 to -4 degrees and from -4 to 4 degrees, respectively. The chop range of -12 degrees corresponds to the asymmetric chopping during the transition from the last +4 degree plateau to the first plaetau at -8 degrees. Note, that while the transition times for a given chopping angle remain constant, the corresponding duty cycle varies for different chopping frequencies. The green lines indicate the specifications for a chop between the calibration sources and a chopping frequency of 4 Hz, the red lines the specifications for a chop inside the sky FOV and a chopping frequency of 4 Hz, too (translated from 10‘Hz specification values).

All measured values in Figure 15 should lie below (left panel), respectively above (right panel) the green and red lines, which, respectively, represent the specified transition time and duty cycle for the ±4 and ±8 degrees chopping. This is obviously not the case. Therefore, the chopper controller parameters used during IST are not suitable to meet the performance specifications. However, they do not represent the meanwhile currently best parameter settings. During ILT3, a significant update of the DECMEC software has been implemented, fixing the restriction that different chopping angles required different control parameters. The new controller software also fixed the small differences in the behaviour between the transitions from a positive into a negative plateau or vice-versa. In the software update, the possibility of using a different resonance suppression filter for the chopper controller was implemented, too. During ILT3, we replaced the notch filter used in this IST test by an elliptical filter, giving a far better chopper stability. The best chopper control parameters after ILT3 are listed in Table 3. An example of the achieved chopper transition behaviour with the new parameter settings can be seen in Figures 16 and 17. The achieved transition times with the ILT3 parameters are 19 ms and 23 ms, for chopping between ±4 and ±8 degrees, respectively. This will be the performance achievable for future IST tests. For chopping between the calibration sources, the achieved transition times are well below the specified 30 ms. For the smaller angles, the achieved transition time is still 9 ms above the specified values. For on sky chopping with a chopping frequency of 4 Hz, the currently best settings can achieve a duty cyle of 80 %. Note, however, that there is a kind of "knee" appearing in the transition shape (left panel of Figure 16). Without this "knee" a much faster transition might be obtained. It is possible that an even more optimal controller parameter set will be found during future testing, resulting in a smoother transition which complies with the specifications.

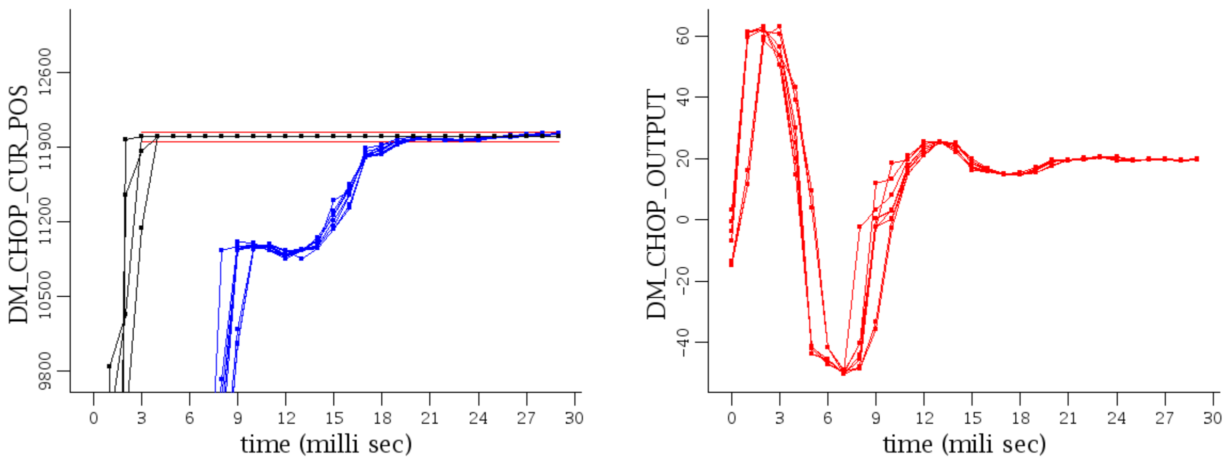

Figure 16: Transition into the positive plateaux for the best chopper controller parameter set after ILT3 for a 4 degree chop. The left panel shows the chopper position. In this panel, the blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits. The right panel shows the output current (in mA) during the transition from negative into positive plateaux.

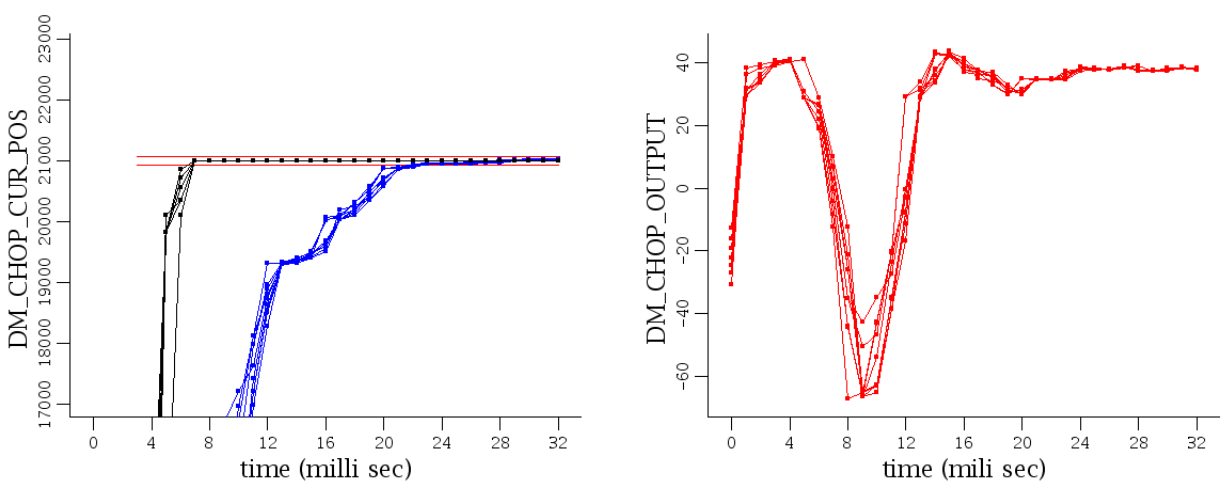

Figure 17: Transition into the positive plateaux for the best chopper controller parameter set after ILT3 for a ±8 degree chop. The left panel shows the chopper position. In this panel, the blue curves show the position readout, the black curves the chopper setpoint. The red lines define the specified plateau accuracy limits. The right panel shows the output current (in mA) during the transition from negative into positive plateaux.

Table 3: Best chopper controller parameters after ILT3

Control parameter	Value Dec.	Value Hex.
Kp	427000	683F8
Ki	25400000	18392C0
Kd	50	32
Kf	2200	898
rate	586	24A
OutLimit	27100	69DC
PosLimit	25000	61A8
Offset	-1195	FFFFFFFB55
KiCurr	289000	468E8
SelectFieldPlateLUT	0	0
FilterN1	101039	00018AAF
FilterN2	171853	00029F4D
FilterN3	101039	00018AAF
FilterD1	1839583	001C11DF
FilterD2	899893	000DBB35
Inductance	148	00000094
Resistance	14650	0000393A
ControlLoopGain	945	000003B1

IMT 504 - G. IA scripts used / remarks on PCSS

We used the following scripts in the pcss system which are checked-in into the cvs path pacs/toolboxes/cal:

Table 4:

PCSS script	functionality
CAP-2.3.2-final-chopper-performance.py	determines the mean plateau and transition times

IMT 504 - H. Lessons learned