

Laboratory Report 0814-11m. Gröna tåget - Regina 250 phase 3 running dynamics tests 2008

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Summary

On assignment from Banverket and KTH, Interfleet technology AB has performed phase 3 of running dynamics tests on Regina 250, a modified Regina train of two cars. During phase 3 soft radially self-steering bogies are tested. In one car (DMA) this is combined with active lateral suspension (ALS).

Tests were performed during the period of 7-24 July and 14 September 2008. Tests are part of the “Gröna Tåget” research and development program.

The vehicle has been tested for a maximum operational speed of 250 km/h and an admissible cant deficiency of 183 mm.

This report covers (1) the acceptance testing according to UIC leaflet 518. The results of this evaluation show that Regina 250 with soft self-steering bogies and active lateral suspension fulfils, under tested conditions, all requirements in UIC 518 for a maximum operating speed of 250 km/h and a maximum operational cant deficiency of 183 mm.

The total number of evaluated test sections is as prescribed in UIC 518, except for large radius curves with the test train running close to admissible cant deficiency. The number of such curve sections could not be fulfilled, basically due to currently a very limited number of such curves in Sweden, where it is possible to accelerate and brake the train in due time.

This report also (2) evaluates dynamic stability at speeds up to around 300 km/h (maximum 303 km/h) on the (mainly) straight line Skövde – Töreboda, partly with a very tight track gauge producing excessive equivalent conicity. The evaluation shows that there are good margins to the stability limit values in the UIC leaflets as measured by lateral track forces.

Finally the report also covers (3) an evaluation of vertical and lateral track forces filtered by a low-pass filter with 140 Hz limit frequency, as a complement to the 20 Hz filtering as specified by UIC. This is for the investigation of “track friendliness” in a higher frequency range.

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CONTENTS

1.	Introduction	6
2.	Test data	6
2.1	The vehicle	6
2.2	Test tracks	7
2.3	Test record	8
2.4	Weather conditions during tests.....	8
2.5	Rail lubrication	8
2.6	Wheel profiles	8
3.	Method	9
3.1	Measured signals	9
3.2	Safety monitoring	10
3.3	Constraints	10
3.3.1	Maximum operational cant deficiency	10
3.3.2	Processing per test zone	10
3.3.3	Curve radii	10
3.3.4	Number of Sections per Radius Class.....	11
3.4	Track quality	12
3.5	Limit values	13
3.6	Presentation.....	14
4.	Results from the UIC 518 evaluation	14
4.1	Bar plot presentations	15
4.2	Safety assessment criteria	15
4.3	Track fatigue related assessment quantities	16
4.4	Running behaviour related assessment quantities	17
5.	High speed stability.....	18
5.1.1	ΣY_{100m} , r.m.s over sliding 100 m	18
5.1.2	$\ddot{y}_{s\ 100m}$, r.m.s over sliding 100 m	19
5.1.3	Investigation of peaks in ΣY_{100m} , r.m.s	19
5.1.4	Equivalent conicity	19
6.	140 Hz band width track forces	20
7.	Discussion	20
7.1	Car body roll	20
8.	Conclusions.....	22
8.1	UIC 518 tests	22
8.2	High speed stability tests	22
9.	References.....	22

APPENDICES

- Appendix 1 – Test record
- Appendix 2 – Transducer positions
- Appendix 3 – List of measured signals
- Appendix 4 – Weighing sheet
- Appendix 5 – Measured wheel profiles
- Appendix 6 – Straight track, leading axle 1
- Appendix 7 – 250 – 400 m radius, leading axle 1
- Appendix 8 – 400 – 600 m radius, leading axle 1
- Appendix 9 – 900 – 1500 m radius, leading axle 1
- Appendix 10 – Large radius, leading axle 1
- Appendix 11 – Straight track, leading axle 8
- Appendix 12 – 250 – 400 m radius, leading axle 8
- Appendix 13 – 400 – 600 m radius, leading axle 8
- Appendix 14 – 900 – 1500 m radius, leading axle 8
- Appendix 15 – Large radius, leading axle 8
- Appendix 16 – Y_{dyn} and Q_{dyn} with 20 and 140 Hz bandwidth
- Appendix 17 – Intentionally left blank
- Appendix 18 – Equivalent conicity
- Appendix 19 – High speed stability summary
- Appendix 20 – High speed stability details
- Appendix 21 – Q_{dyn} with 140 Hz bandwidth, high peaks time series

1. Introduction

The Gröna Tåget project team consisting of Banverket, KTH Technical University and Bombardier Transportation, seek to build and prove a radial steering bogie applied to the existing “Regina” train design. Interfleet has provided support for testing for the project. The phases 1 and 2 of testing was done in 2006 and 2007 using a Regina with modified bogies and primary suspension using passive self-steering as well as active radial steering. During phase 3 done in 2008 the combination of active lateral suspension and radial self steering was tested. Interfleet Technology AB (ITAB) was contracted to perform running dynamics tests, mainly according to the leaflet UIC 518.

This report covers general information of the tests as well as the results from the evaluation of the running dynamics tests.

2. Test data

2.1 The vehicle

The test object was the “Regina” train X52 9062, which was rebuilt and after the rebuild called Regina 250. The trainset consists of two cars, Figure 1. The new bogie was, from a vehicle dynamics point of view, the most important difference compared with the original vehicle. The new bogie design aimed to increase the service speed from 200 km/h to at least 250 km/h. All gears were changed to allow the higher speed. The primary suspension and wheelset guidance was modified to ensure running stability at the higher speed, yet allowing good curving performance. One of the cars (DMA) had devices for active lateral suspension in both bogies.



Figure 1 **Layout of Regina 250**

The testvehicle was run using its own motor power, and no other vehicles were part of the test train.

The vehicle including bogies, wheels etc were tested as delivered by the customer, except for the instrumented wheels capable of measuring lateral and vertical wheel-rail forces, which were manufactured by ITAB.

• Type of vehicle:	Regina 250, X52 9062
• Length of the vehicle:	2 * 26.95 m
• Gross weight:	61.7 + 60.1 tonnes
• Axle load:	14.7 – 15.8 tonnes
• Maximum permitted operational speed:	250 km/h
• Maximum operational cant deficiency:	183 mm

Table 1 **Data of vehicle**

2.2 Test tracks

Test runs were performed on the following lines:

- Grillby – Västerås N
- Sala – Morgongåva
- Uppsala – Gävle – Sundsvall
- Sundsvall – Ånge (by triangulations both vehicle ends leading in both directions)
- Järna – Nyköping
- Järna – Katrineholm – Hallsberg – Töreboda – Skövde

In the plots abbreviations for station names are used according to Table 2.

Station	Abbreviation
Falköping	F
Grillby	Gib
Gnarp	Gnp
Gnesta	Gn
Gävle	Gä
Hallsberg	Hpbg
Hudiksvall	Hkl
Järna	Jn
Katrineholm	K
Laxå	Lå
Morgongåva	Må
Nyköping	Nk
Ransta	Rt
Regumatorp	Rmtp
Sala	Sl
Skutskär	Sur
Skövde	Sk
Stöde	Std
Sundsvall	Suc
Töreboda	T
Vattjom	Vm
Västerås C	Vå
Uppsala C	U
Ånge	Åg
Örbyhus	Öh
Örebro	Ör

Table 2 Station name abbreviations

2.3 Test record

In Appendix 1 there is information for tracks, test numbers et cetera.

- Line is a code number for the railway line used in the test. See Table 3.
- UNE in the table shows whether the test is run on single track (E), up track (U/U1) or down track (N/N1).
- Friction is an estimate of the friction done by the drivers when applying tractive forces.
- Trainconfig: +1 = DMA is facing in the direction of increasing kilometres of the line, -1 = DMA is facing in opposite direction irrespective of travel
- Revision is the revision number of setup for the data acquisition systemLine no.

	Description
0	Main line North: Stockolm – Boden
2	Järna – Nyköping – Åby
3	Main line West: Katrineholm – Gothenburg
5	Main line South: (Stockholm) – Järna – Katrineholm
6	(Stockholm) – Karlberg – Västerås – Kolbäck
17	East coast line: Uppsala – Sundsvall
39	“Mittlinjen”: Ånge – Sundsvall

Table 3 Line number coding in the test record

2.4 Weather conditions during tests

The weather was generally dry, with temperatures ranging from +18 to +26°C during daytime and down to +10°C at night. The wheel-rail friction was, with a few exceptions, high. The drivers of the train continuously estimated and reported the friction conditions.

2.5 Rail lubrication

Trackside rail lubrication equipment between Stöde and Vatjom was shut down about two weeks before the tests. This applies to the test zone with 250 – 400 m curve radii. Sections in the 400 – 600 m curve radii test zone may be affected by lubrication in some cases.

2.6 Wheel profiles

The wheel profiles were slightly worn S1002 with 32.5 mm flange thickness, see Appendix 5. The wheel profiles were measured with the wheels mounted under the vehicle in tare condition axle load.

The instrumented wheelsets were intentionally mounted on the axles with a back to back distance of 1361.5 mm instead of nominal 1360 mm used on all other axles in the train set. The purpose of this was to increase the equivalent conicity to about 0.3 in order to provoke

any tendencies of instability. An equivalent conicity of 0.3 is the upper limit for vehicles approved for a permissible operational speed of up to 250 km/h, according to the leaflet UIC 518.

The equivalent conicity has been computed for the real combination of wheels and rails on the up-track Töreboda – Skövde as described in 5.1.4 below. Examples of deltaR functions etc are presented in Appendix 18.

3. Method

3.1 Measured signals

The instrumentation setup was unchanged during the series of tests. During the initial tests on lines Grillby – Västerås and Sala – Morgongåva only part of the setup was active. See Appendix 2 for transducer positions.

- Two instrumented wheelsets, measuring lateral and vertical wheel-rail forces.
- Six accelerometers mounted on the bogie frames, measuring lateral accelerations. The accelerometers were positioned close to axles 1, 2, 3, 4, 5, and 8.
- Two accelerometers in each car body over each of the four bogies, measuring lateral and vertical accelerations.
- One extra lateral accelerometer mounted over the hat rack in DMB to get the roll angle.²
- Three accelerometers in the DMA car body in the middle between the bogies, triaxial.
- One vertical accelerometer in the DMB car body in the middle between the bogies.
- One axle box mounted accelerometer on the left hand side of axle 2 measuring uncompensated lateral acceleration in the track plane.
- One gyro for roll rate in DMB
- Six displacement transducers to measure vertical and lateral bogie displacements in relation to the car body, see appendix 2.2-3.
- GPS receivers both in DMA and DMB for positioning and speed.
- One Doppler radar for speed.
- Eight analogue signals from Bombardier active lateral suspension system in DMA.

The car body accelerometers were for practical reasons mounted with a lateral offset dy , see Table 4.

Name	dy
y..*1I	0.83
z..*1I	0.83
x..*1M	-0.87
y..*1M	-0.87
z..*1M	-0.87
y..*1II	-0.83

Name	dy
z..*1II	-0.83
y..*2I	0.72
z..*2I	0.72
z..*2M	0.67
y..*2II	0.6
z..*2II	0.6

Table 4 Car body accelerometers lateral offset.

² Positioned 1.47 m to the right from the center line and 1.53 m over the floor level

All measured signals were digitised and stored in the Interfleet Technology AB measurement system based on MGCplus from Hottinger Baldwin Messtechnik GmbH, see Appendix 3. Depending on the frequency range, the signals were sampled with 600 or 300 Hz. The anti aliasing filters were set to a cut-off frequency defined by the 3 dB attenuation point to 250 or 50 Hz³. These filters were 4 poles Butterworth type.

Some of the signals, in particular accelerometers in car bodies, are not evaluated in this report

3.2 Safety monitoring

The safety related parameters were constantly monitored in real time using a separate data acquisition system. This system did not store any raw data, all post processing use data from the ordinary system.

3.3 Constraints

3.3.1 Maximum operational cant deficiency

The vehicle has been tested for a maximum operational cant deficiency $I_{adm} = 183$ mm. In the leaflet UIC 518, see Appendix C the cant deficiency value to be taken into account for train category III – Non tilting multiple units is maximum 165 mm.

3.3.2 Processing per test zone

In the statistical processing per test zone the one-dimensional method was used to estimate the maximum value of the assessment quantities for straight track and in the zone with 400-600 m curves. The reason for this is that the statistical properties of the population generated for this test zone causes a substantial over-estimation of the maximum values. For the remaining zones with curves the two-dimensional statistical method was used.

3.3.3 Curve radii

One extra curve radius class $900 \leq R \leq 1500$ m have been included in the evaluation. Most of the curves in the $900 \leq R \leq 1500$ class have radii close to 1000 m. There also are two curves of 1169 m and one of 1486 m radius present.

³ In Appendix 3 a cut-of frequency of 300 or 40 Hz at 1 dB attenuation is shown, this is equal to 250 or 50 Hz at 3 dB attenuation

3.3.4 Number of Sections per Radius Class

The number of sections used for evaluation is as presented in Table 5.

In the large radii test zone the number of sections is insufficient.

Leading axle		Straight track	$250 \leq R < 400$ m	$400 \leq R \leq 600$ m	$900 \leq R \leq 1500$ m	Large-radius curves
1	Total	39(25)	32(25)	59(50)	38	8(25)
	$1.1 \cdot I_{adm}$	-	4(6)	12(18)	14	3(5)
8	Total	39(25)	31(25)	83(50)	39	16(25)
	$1.1 \cdot I_{adm}$	-	2(6)	37(17)	23	5(5)

Table 5 Number of sections in evaluation. Number of sections prescribed in UIC518 in parenthesis.

In the leaflet UIC 518, it is required that at least 20% of all sections in respective test zone shall have a cant deficiency of $(1.05 - 1.15) \cdot I_{adm}$. This is only fulfilled in the $400 \leq R \leq 600$ m test zone. No safety related assessment criterion is close to the limit value, as seen in Section 4.2 tables.

3.4 Track quality

In UIC 518, it is suggested, but not mandatory, that the test sections have a certain distribution of geometric quality, and that the distribution is graphically revised. In this report, the proportions of track used in different quality classes defined in the leaflet UIC 518 are presented in Table 6.

The figures are the relative share of each track quality levels in percent of all sections in a certain zone. Also the recommended distribution is shown. The track quality is far better than recommended in the leaflet.

Quality levels:

QN1 – Equal or better than QN1

QN2 – Between QN1 and QN2

QN3 – Between QN2 and QN3

Alignment	Quality level	Recommended distribution	Straight track	$250 \leq R < 400$ m	$400 \leq R \leq 600$ m	$900 \leq R \leq 1500$ m	Large-radius curves
NL std Vertical	QN1	50	64	87	83	77	100
	QN2	40	28	13	15	16	0
	QN3	10	8	0	2	8	0
D std Lateral	QN1	50	81	13	90	95	100
	QN2	40	19	27	10	5	0
	QN3	10	0	60 ⁴	0	0	0

Table 6 Track quality percentage distribution for the test zones

⁴ The lateral track quality distribution has a surprisingly overweight to QN3 in the $250 \leq R < 400$ m test zone. Track quality evaluation is based on a line speed of 75-100 km/h, although this track is classified by Banverket for a line speed up to 70 km/h.

3.5 Limit values

The limit values based on 15.8⁵ tonnes axle load are as follows:

(“UIC no” refers to the number in the table on page 56-57 of the leaflet. Name in plot indicates where to find a plot showing the value in the appendices. All plot appendices have similar structure.)

Description Name in plot	Denotation	Limit value	UIC no
Track shift force S1 2m 99.85%, S1 2m 0.15% – axle 1 S2 2m 99.85%, S2 2m 0.15% – axle 2	ΣY_{2m}	61.7 kN	1
Flange climbing quotient Y/Q11, Y12 2m 99.85 – axle 1 Y/Q21, Y22 2m 99.85 – axle 2	$(Y/Q)_{2m}$	0.8	2
Sliding r.m.s. of track shift force	ΣY_{100m}	30.8 kN	10

Table 7 Limit values for safety related assessment quantities

Description Name in plot	Denotation	Limit value	UIC no
Vertical dynamic wheel rail force Q11, Q12, Q21, Q22 20Hz LP 99.85%	Q	167.5 kN	5
Lateral quasistatic wheel rail force Y11, Y12 20Hz LP Average – axle 1 Y21, Y22 20Hz LP Average – axle 2	Y_{qst}	60 kN	6
Vertical quasistatic wheel rail force Q11, Q12, Q21, Q22 20Hz LP Average	Q_{qst}	145 kN	7

Table 8 Limit values for track fatigue related assessment quantities

⁵ Weighing was done on the weight bridge in Bombardier lok-vst sp 7, see Appendix 4. The axle load was estimated to be about 200 kg higher during the tests due to increased weight of equipment and personnel. The limit values are adjusted accordingly.

Description Name in plot	Denotation	Limit value	UIC no
Max value car body lateral acceleration y..*1I 0.4-10Hz BP 99.85% 0.15% – over bogie 1 y..*1II 0.4-10Hz BP 99.85% 0.15% – over bogie 2	\ddot{y}_q^*	2.5 m/s ²	8
Max value car body vertical acceleration z..*1I 0.4-10Hz BP 99.85% 0.15% – over bogie 1 z..*1II 0.4-10Hz BP 99.85% 0.15% – over bogie 2	\ddot{z}_q^*	2.5 m/s ²	8
r.m.s. value car body lateral acceleration y..*1I 0.4-10Hz BP Std – over bogie 1 y..*1II 0.4-10Hz BP Std – over bogie 2	$s\ddot{y}_q^*$	0.5 m/s ²	8
r.m.s. value car body vertical acceleration z..*1I 0.4-10Hz BP Std – over bogie 1 z..*1II 0.4-10Hz BP Std – over bogie 2	$s\ddot{z}_q^*$	0.75 m/s ²	8
Quasistatic lateral car body acceleration y..*1I Average – over bogie 1 y..*1II Average – over bogie 2	\ddot{y}_{qst}^*	1.5 m/s ²	9

Table 9 Limit values for running behaviour related assessment quantities

3.6 Presentation

Appendices 6 to 15 contain results from the evaluation according to the leaflet UIC 518. The following structure has been used, appendices are grouped five and five.

1 st	Straight track
2 nd	Full curves: 250m ≤ radii < 400m.
3 rd	Full curves: 400m ≤ radii ≤ 600m.
4 th	Full curves: 900m ≤ radii ≤ 1500m.
5 th	Full curves: Large-radius curves

4. Results from the UIC 518 evaluation

The evaluation has been performed according to the leaflet UIC 518, with limit speed $V_{lim}=250$ km/h and cant deficiency $I_{adm}=183$ mm. In the statistical processing per section the 0.15, 50 or 99.85 centiles of the histograms or the r.m.s. value are derived. In the tables below the estimated maximum value of the assessment quantities for each test zone are computed as

$\hat{x}_{max} = \bar{x} + k \cdot s$ ⁶. In the statistical processing per test zone the one-dimensional method was used to estimate the maximum value of the assessment quantities for straight track and the zone with 400-600 m curves. The two-dimensional method has been used in the test zones with 250-400 m, 900-1500 and large radius curves.

⁶ For the one-dimensional method, \bar{x} is the mean value, s the standard deviation for the derived values in each test zone. k is the coef. k in UIC 518 Appendix F. For the two-dimensional method a 95 or 99% confidence interval is used instead of $k=2.2$ or 3.0 .

4.1 Bar plot presentations

For detailed results all UIC 518 bar plots are found in Appendix 6 to 15.

In appendices 6 to 15 the abbreviation “external in curve sel.” can be seen. This indicates that the appropriate percentile (99.85% or 0.15%) has been selected for the plot depending on the curve direction.

4.2 Safety assessment criteria

The results for safety related assessment criteria are as follows⁷:

Quantity tested	Test zone	Max Estimated Value [kN]	Percentage of Limit	Max Measured Value [kN]
Y/Q	$250 \text{ m} \leq R < 400 \text{ m}$	0.68	85	0.61
	$400 \text{ m} \leq R \leq 600 \text{ m}$	0.65	81	0.61
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	0.46	58	0.45
	Large-radius curves	0.28	35	0.24
ΣY [kN]	Straight track	34	55	28
	$250 \text{ m} \leq R < 400 \text{ m}$	40	65	37
	$400 \text{ m} \leq R \leq 600 \text{ m}$	40	65	36
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	40	65	42
	Large-radius curves	44	71	37

Table 10 Estimated maximum safety related assessment criteria, as absolute values and as percentage of the limit values

As seen in the columns Percentage of Limit all safety related quantities are well within the limits.

The highest results from the Normal Method stability evaluation are shown in Table 11:

Test	Stations	Track	Kmp	Speed [km/h]	Eigen frequency	ΣY_{100m} [kN]
246	Rmtp-T	U	~301+250	276	5.5	16

Table 11 Instability criterion ΣY r.m.s over 100 m sliding window

As can be seen in Table 11 the results for ΣY_{100m} are very far from the limit value 30.8 kN.

⁷ Max estimated values are calculated as mean+3*standard deviation. This corresponds to the 99.85 percentiles if measured quantities have normal distributions. There is a risk that variations in measured values, due to different test speed and cant deficiency cause a high standard deviation and thus an unrealistic high estimated value. Therefore also the max measured value, taken from the bar plots are indicated in Table 10, as additional information.

4.3 Track fatigue related assessment quantities

The results for track fatigue related assessment criteria are as presented in Table 12. The two left columns are evaluations according to UIC 518. The right column presents forces with 140 Hz low-pass filtering instead of 20 Hz as specified by UIC 518.

Quantity tested	Test zone	Max Estimated Value [kN]	Percentage of Limit	Max Estimated Value 140 Hz (1-dim) [kN]
Y [kN]	$250\text{m} \leq R < 400\text{m}$	68	-	70
	$400\text{ m} \leq R \leq 600\text{ m}$	40^8	-	61
	$900\text{ m} \leq R \leq 1500\text{ m}$	44	-	47
	Large-radius curves	28	-	29
Q [kN]	Straight track	100	60	169
	$250\text{m} \leq R < 400\text{m}$	113	67	127
	$400\text{ m} \leq R \leq 600\text{ m}$	118	70	176
	$900\text{ m} \leq R \leq 1500\text{ m}$	121	72	168
	Large-radius curves	119	71	141
Y_{qst} [kN]	$250\text{ m} \leq R < 400\text{ m}$	44	73	-
	$400\text{ m} \leq R \leq 600\text{ m}$	27	44	-
	$900\text{ m} \leq R \leq 1500\text{ m}$	18	30	-
Q_{qst} [kN]	$250\text{ m} \leq R < 400\text{ m}$	102	71	-
	$400\text{ m} \leq R \leq 600\text{ m}$	98	68	-
	$900\text{ m} \leq R \leq 1500\text{ m}$	102	71	-

Table 12 Estimated maximum track fatigue related assessment criteria, as absolute values and as percentage of the limit values

As seen in the columns Percentage of Limit all track fatigue related quantities are well within the limits.

⁸ One dimensional estimate

4.4 Running behaviour related assessment quantities

The results for running behaviour related assessment criteria are as follows:

Quantity tested	Test zone	Max Est. Value	Percentage of Limit
\ddot{y}_q^*	Straight track	0.96	38
	$250 \text{ m} \leq R < 400 \text{ m}$	0.47	19
	$400 \text{ m} \leq R \leq 600 \text{ m}$	0.46	18
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	0.95	38
	Large-radius curves	0.81	32
$\ddot{z}_q^{*,*}$	Straight track	1.7	68
	$250 \text{ m} \leq R < 400 \text{ m}$	0.43	17
	$400 \text{ m} \leq R \leq 600 \text{ m}$	0.63	25
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	0.96	38
	Large-radius curves	0.50	20
$s\ddot{y}_q^*$	Straight track	0.34	68
	$250 \text{ m} \leq R < 400 \text{ m}$	0.16	32
	$400 \text{ m} \leq R \leq 600 \text{ m}$	0.15	30
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	0.25	50
	Large-radius curves	0.23	46
$s\ddot{z}_q^{*,*}$	Straight track	0.51	68
	$250 \text{ m} \leq R < 400 \text{ m}$	0.17	23
	$400 \text{ m} \leq R \leq 600 \text{ m}$	0.24	32
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	0.30	40
	Large-radius curves	0.15	20
\ddot{y}_{qst}^*	$250 \text{ m} \leq R < 400 \text{ m}$	1.37/1.59	91/106
	$400 \text{ m} \leq R \leq 600 \text{ m}$	1.35/1.59	90/106
	$900 \text{ m} \leq R \leq 1500 \text{ m}$	1.45/1.58	97/104
	Large-radius curves	1.42/1.60	95/107

Table 13 Estimated maximum running behaviour related assessment criteria as percentage of the limit values.

As seen in the columns Percentage of Limit, with the exception of \ddot{y}_{qst}^* , the running behaviour related quantities are well within the limits.

The estimated max value for \ddot{y}_{qst}^* is computed with the one-dimensional as well as the two-dimensional method. In Table 13 the results for the two methods is separated with a "/". The two-dimensional method gives an estimated max value 104-107 % of the limit value. This is discussed further in section 7.1.

5. High speed stability

On the line between Skövde and Töreboda the stability on mainly straight track was tested at a maximum speed of up to 303 km/h on the up-track and 295 km/h on the down-track. This is considerably higher than the test speed 275 km/h stipulated in the leaflet UIC 518 for straight track when the limit speed is $V_{lim}=250$ km/h.

5.1.1 ΣY_{100m} , r.m.s over sliding 100 m

During test no. 626 performed on the up-track with a maximum speed of 303 km/h the highest recorded ΣY_{100m} was 18 kN. This is far from the limit value 30.8 kN in the leaflet UIC 518 and in fact only slightly higher than recorded in the UIC 518 tests speed 276 km/h recorded during test no. 246, see Table 11.

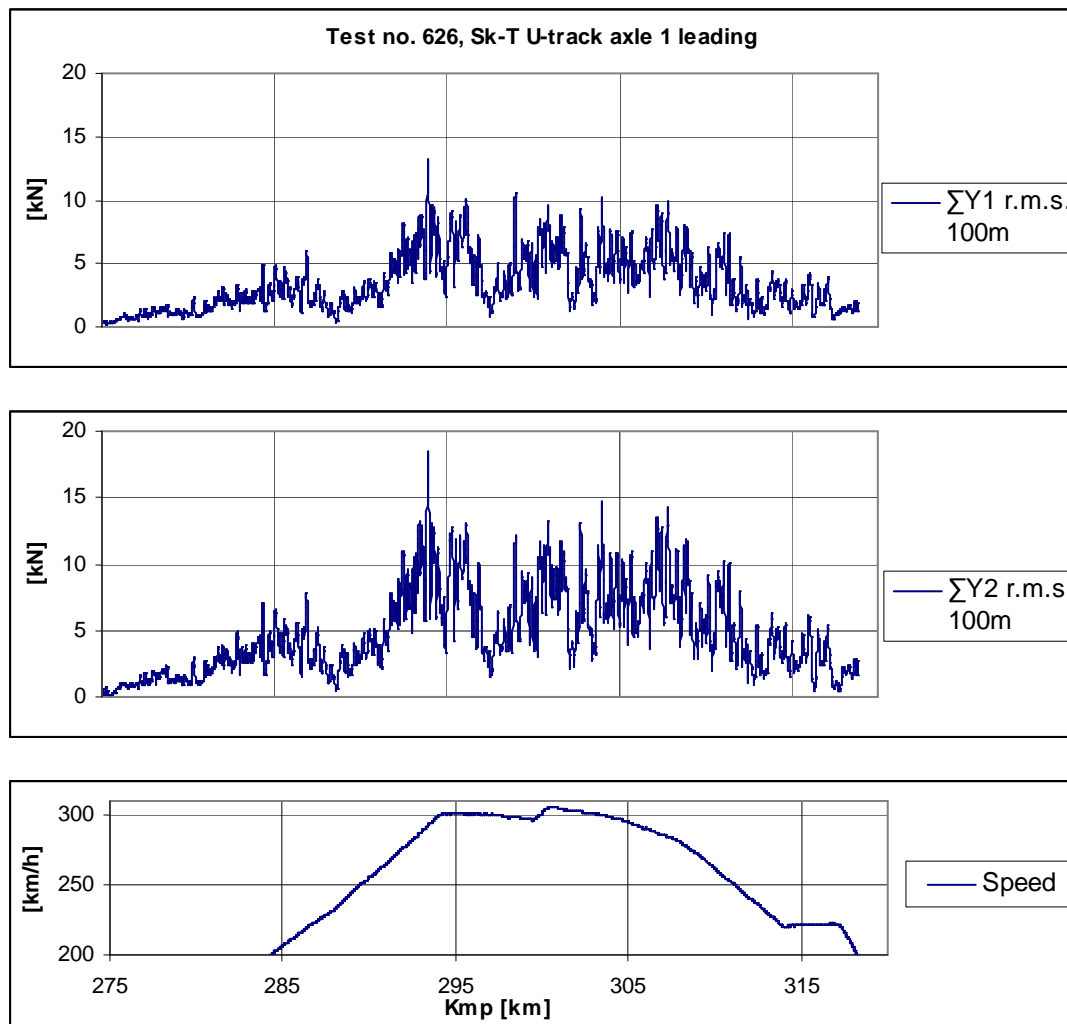


Figure 2 ΣY_{100m} , r.m.s over sliding 100 m Skövde – Töreboda axle 1 leading

5.1.2 $\ddot{y}_{s\ 100m}$, r.m.s over sliding 100 m

Highest $\ddot{y}_{s\ 100m}$ was recorded in test 626 at 300 km/h directly before coasting was commenced. The highest observed r.m.s. value came from the accelerometer above axle 2, the reading was 7.2 m/s^2 . This is slightly exceeding $0.5 \cdot (12 - M_b/5)\text{ m/s}^2$ (M_b =bogie weight) as is the limit value for the simplified method in the leaflet.

5.1.3 Investigation of peaks in ΣY_{100m} , r.m.s

In order to show reasons for the peaks seen in Figure 2 ΣY_{100m} , r.m.s over sliding 100 m Skövde – Töreboda axle 1 leading, the track shift force ΣY and the lateral bogie accelerations are presented as time series versus the kilometre pole position in Appendix 20. The signals in the appendix are band-pass filtered according to the stability criterion in the leaflet but they are not averaged over 100m. Details over the peaks at kmp 303 and 294 are also shown in Appendix 20.

During test no. 624 the main circuit breaker (MSB) switched off the main power supply and the test was terminated at kmp 303. Comparing Appendix 20 Page 2 and Page 5, the signal pattern for the two tests are identical between kmp 305 – 304+500. From kmp 304+500 the stability for DMA was much poorer for the test when the MSB switched off. The DMB coach was unaffected by the effects of this switch off. Signal pattern for the accelerometers in DMB are similar for the hole section between kmp 305 – 302.

The reason for the deteriorated stability of DMA⁹ is likely that the active lateral suspension (ALS) became unpowered when the MSB opened, causing that its lateral damping effect suddenly disappears. There is no ALS in the DMB coach; but a conventional lateral damper without need for power supply.

5.1.4 Equivalent conicity

Applying software for UIC 519 validation the equivalent conicity is computed. As input data, rail profiles, one profile for each 5 metre measured by Banverket's STRIX track recording car on July 15 2007 and SPAK wheel profiles from axle 1 and 3 recorded 2007, is used. The wheel profiles for axle 1 were measured without load from the vehicle. Therefore the treads of those profiles were transformed (rotated) under the assumption that the back to back distance is reduced by 1 mm when the axle is loaded. In the computation a back to back distance 1361 mm was used for axle 1 and 1360 mm for axle 3. The rail inclination, 1:30 as usual for the Swedish network, is included in the STRIX data.

⁹ It should be noted that the equivalent conicity in the wheel-rail interface is excessively high, see Figure 3. The conicity on this section of the line has an average of about 0.5 with peaks up to 0.8. According to UIC 518 the limit value in this speed range is 0.25. Despite the high conicity and despite the deteriorated stability of DMA, there are still margins to the limit value for ΣY_{100m} r.m.s.

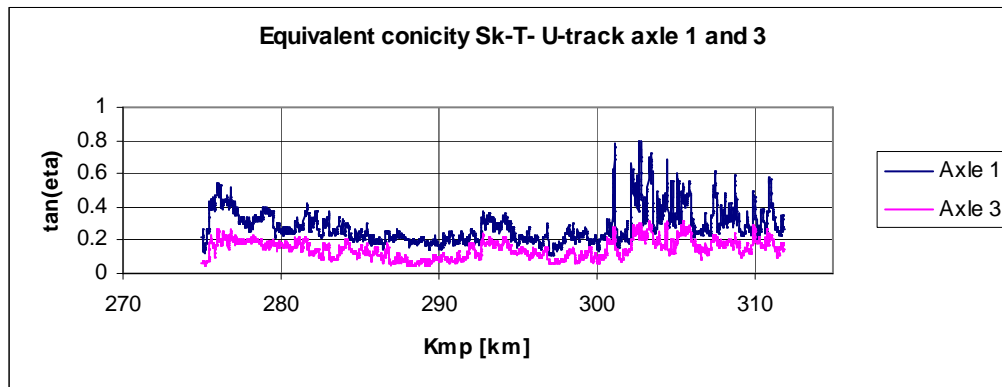


Figure 3 Equivalent conicity U-track Töreboda – Skövde.

In Figure 3 the median over a 100 m sliding window is shown. The reason for using the median is that the equivalent conicity is highly non-linear and sensitive to erratic rail profiles. Under these circumstances the median is more reliable than the mean value. As example in Appendix 18 deltaR functions and some contact point geometries are shown for axle 1 and axle 3, computed with two of the measured real rail profiles. The first of the shown example is taken where the track gauge was 1429mm and the second where the gauge was 1432mm.

6. 140 Hz band width track forces

In order to investigate the “track friendliness” in a higher frequency range the vertical and lateral track forces also have been analyzed with 140 Hz band width in addition to the normal 20 Hz in UIC 518, see appendix 16. This analysis is done on the same sections and with the same methodology as for the UIC 518 evaluation. When estimating the maximum values presented in Table 12 the one-dimensional method has been used with $k=2.2$.

Especially in the test zone with 400 – 600 m radius curves there are some sections with high Q 99.85% values, see Appendix 16.6 and 16.16. The highest peak for leading axle 1 is shown as time series in Appendix 21.1. The reason for the Q forces getting high is presumably corrugated railheads.

In the 900 – 1500 m radius test zone there also are some sections with high Q 99.85% values. Two of these are shown as time series in Appendix 21 page 2. These cases show a transient behaviour in the Q force. The reason could be worn switches and crossings, but this is not investigated in detail.

7. Discussion

7.1 Car body roll

The quasistatic car body lateral acceleration \ddot{y}_{qst}^* is a resultant of two components, the cant deficiency and the car body roll. Due to the high cant deficiency¹⁰ there is only a small margin left for the body rolling outwards. Using the two-dimensional estimated max value this margin is insufficient for $I_{adm}=183$ mm in curves negotiating the cant deficiency. On the other hand

¹⁰ See 3.3.1 Maximum operational cant deficiency

the one-dimensional estimated values are lower than the limit value¹¹. The reason for this is that the two dimensional method makes the estimation at $1.1 \cdot I_{adm}$ and the one dimensional $1.0 \cdot I_{adm}$.

In the case of quasi-static lateral acceleration in vehicle body ($y_{..qst}$) the evaluated values reaches 90-97 % of the stipulated limit values. This is as evaluated with the one-dimensional method as stipulated in UIC 518. The average cant deficiency of the evaluated tests is 93-98 % of the admitted cant def.

An additional evaluation has been performed with the two-dimensional method at a cant deficiency = I_{adm} . This results in values of $y_{..qst}$ of 90 - 100 % of the limit value. This means that the lateral acceleration in the carbody is close to the limit value at an admitted cant deficiency of 183 mm¹².

¹¹ According to UIC 518 4th edition, May 2007, 9.2 – Statistical processing per zone, "Estimated quasi-static quantities shall be calculated by the two-dimensional method."

¹² UIC 518 is valid for an admitted cant deficiency of 165 mm in the speed interval $0 < V \leq 160 \text{ km/h}$ and 150 mm in the interval $160 < V \leq 250 \text{ km/h}$.

8. Conclusions

8.1 UIC 518 tests

Regina 250 with “soft” radial self steering bogies and active lateral suspension fulfils, under the tested conditions, all requirements in UIC 518, 2nd edition for a maximum operating speed of 250 km/h and a maximum operational cant deficiency of 183 mm.

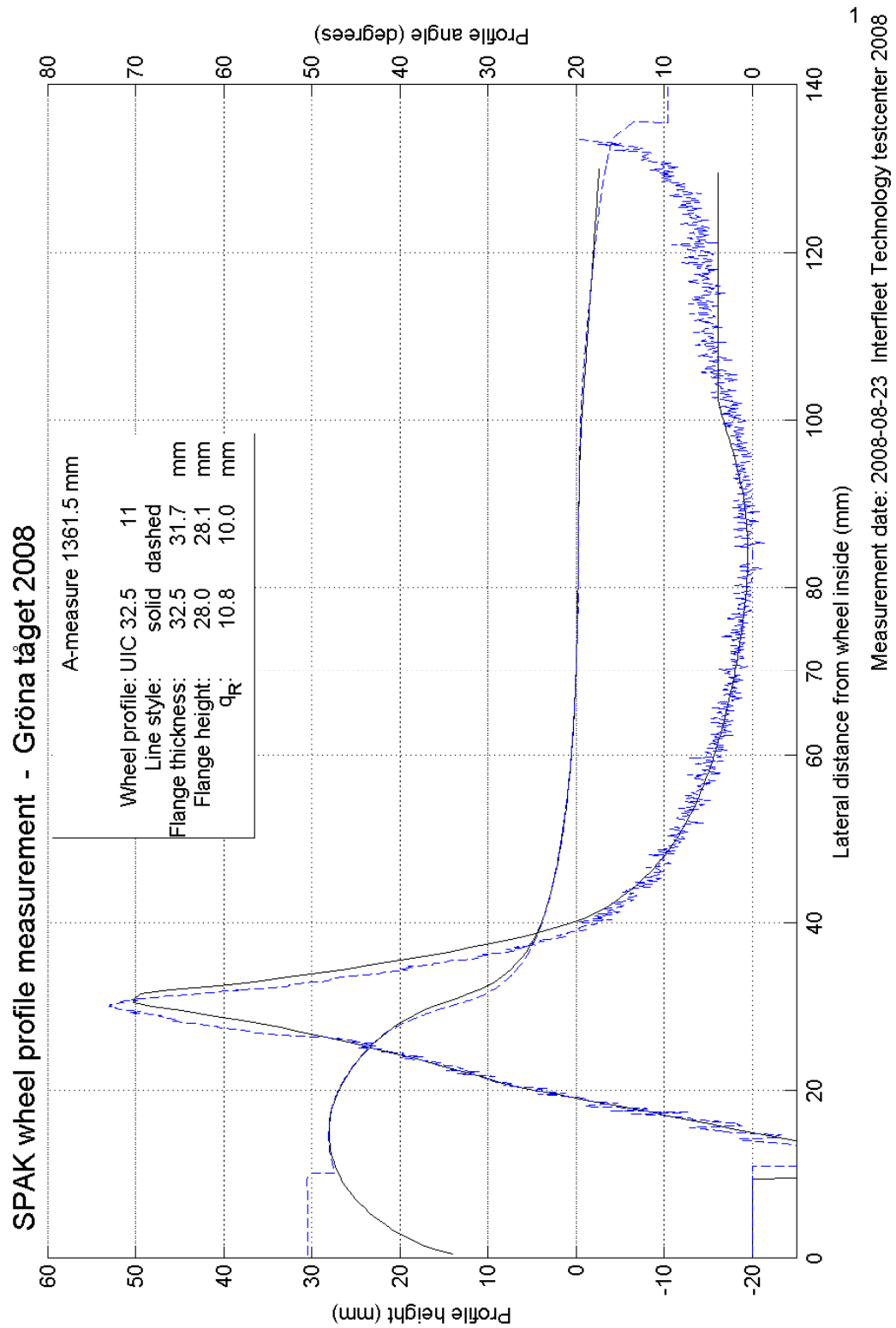
8.2 High speed stability tests

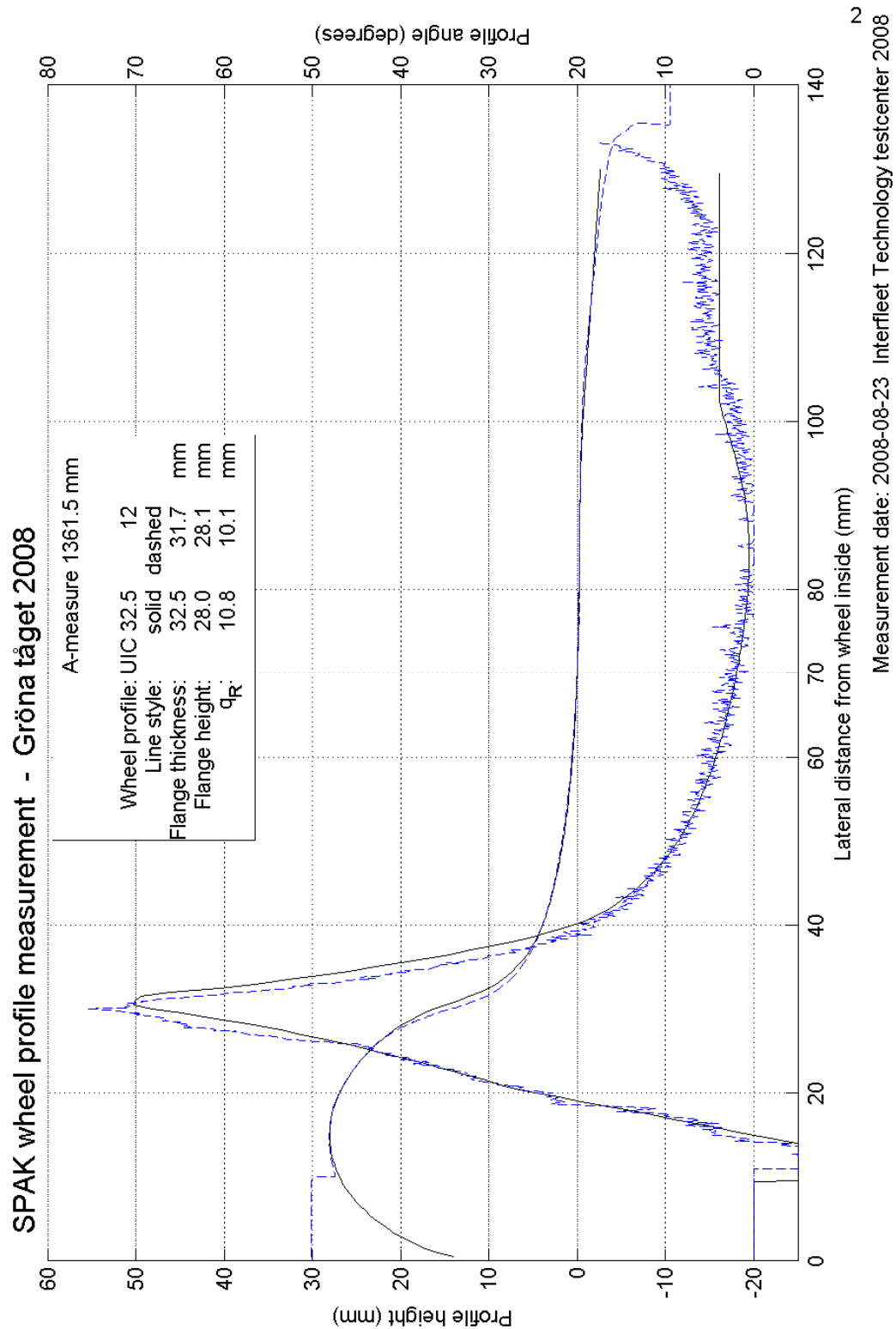
The stability evaluation of the high speed tests shows that up to the maximum tested speed, 303 km/h, there are good margins to the stability limit values in the UIC 518, as measured by the normal method of track forces.

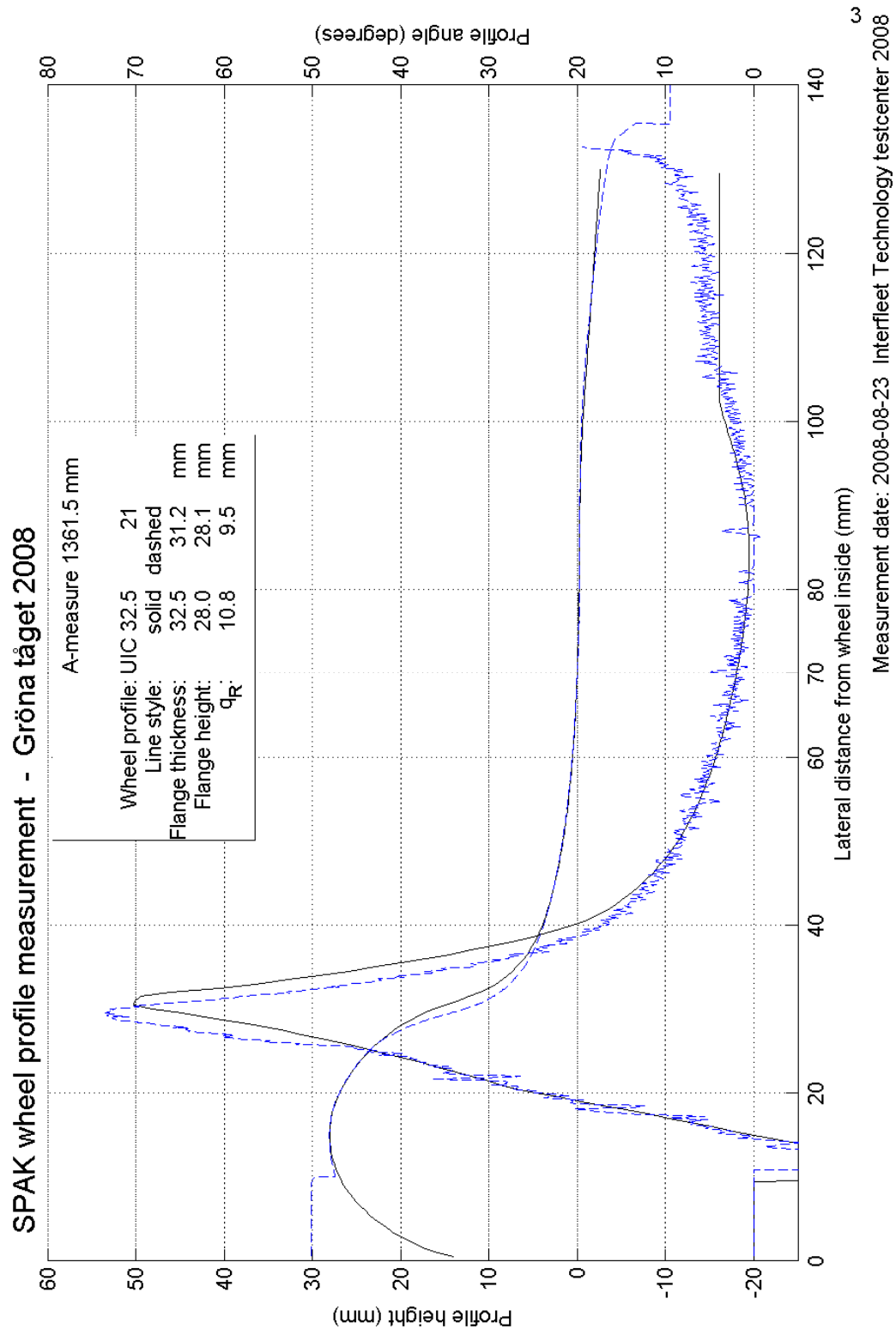
9. References

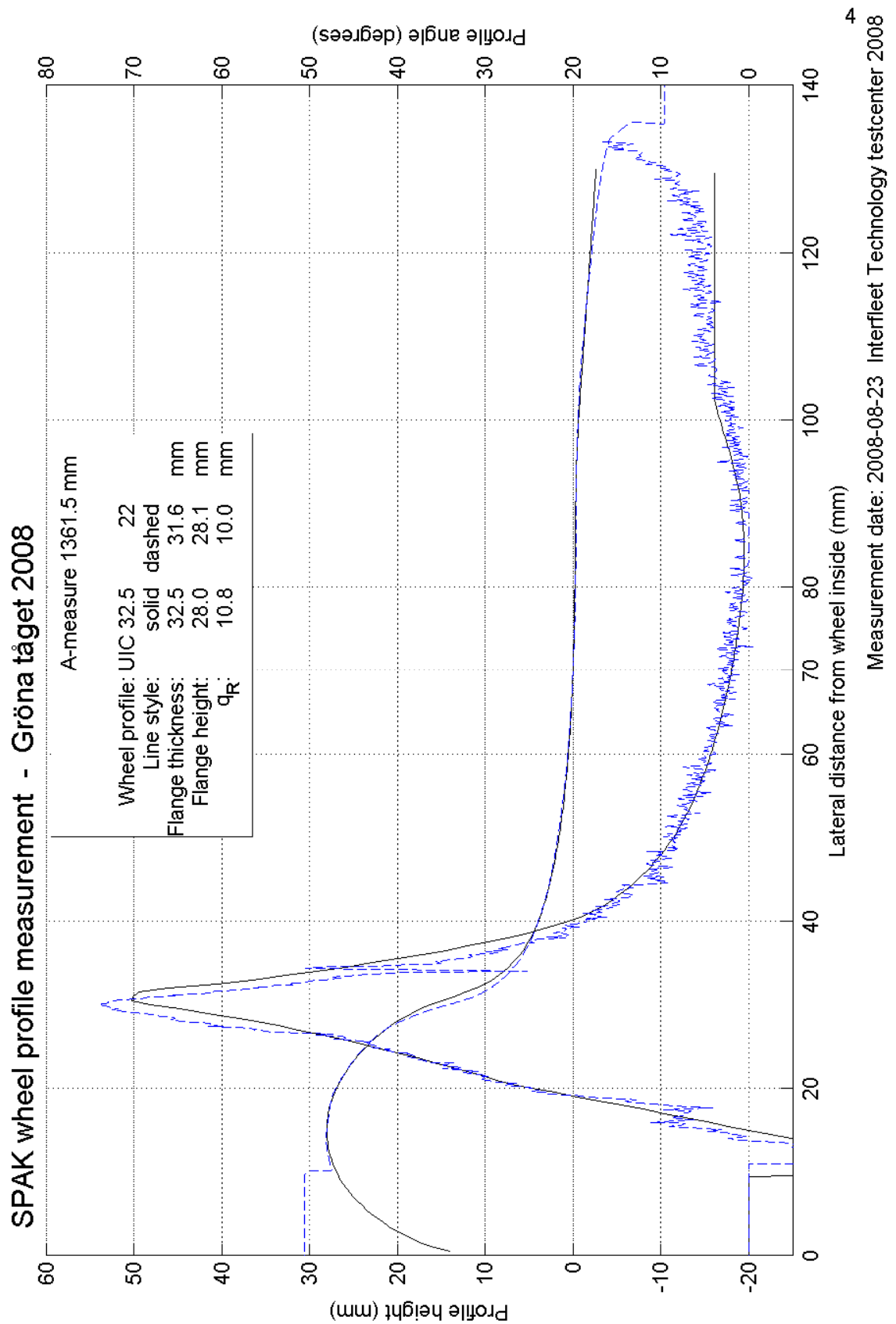
- [1] UIC 518, 2nd edition, April 2003.

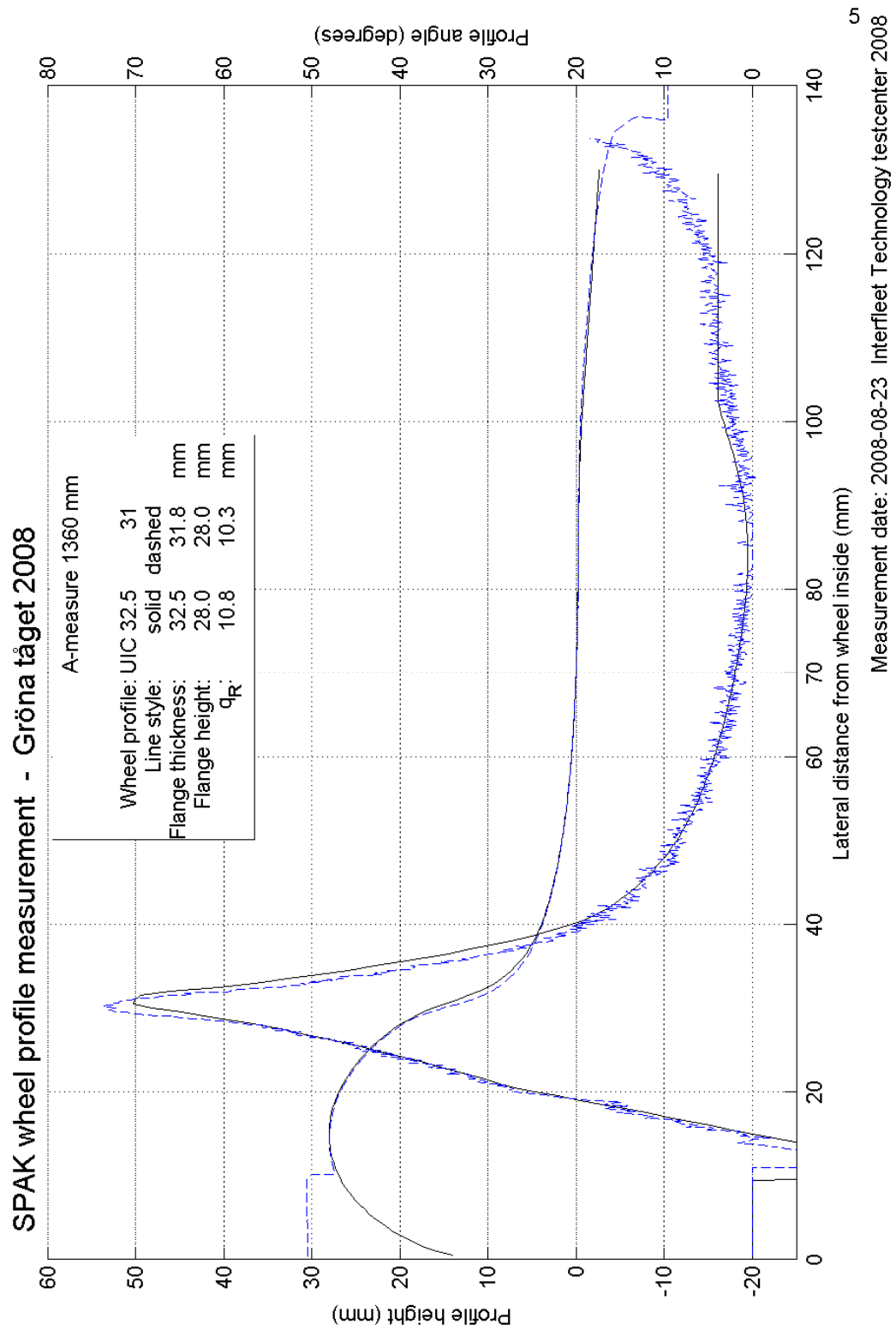
Appendix 5: Wheel profiles

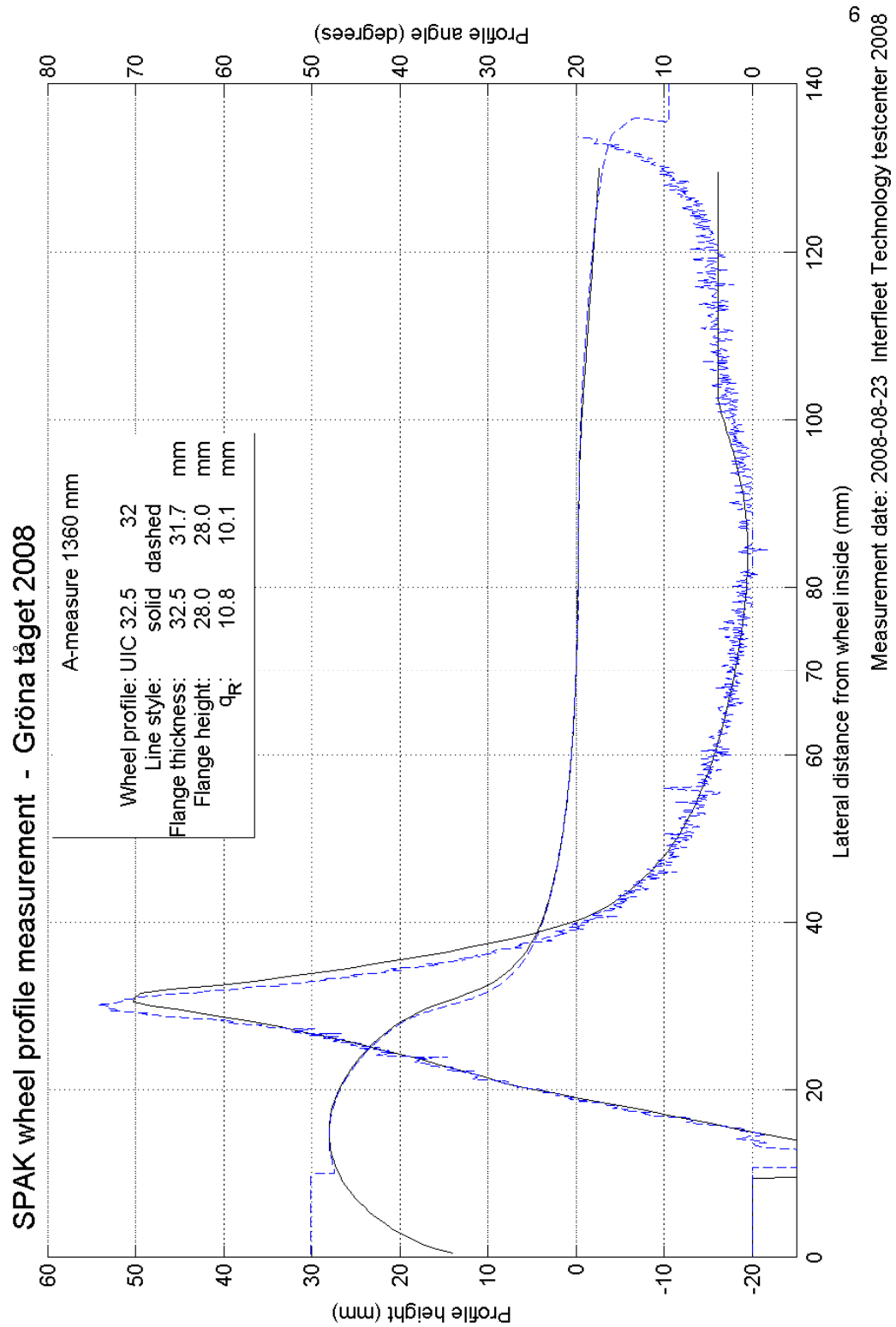


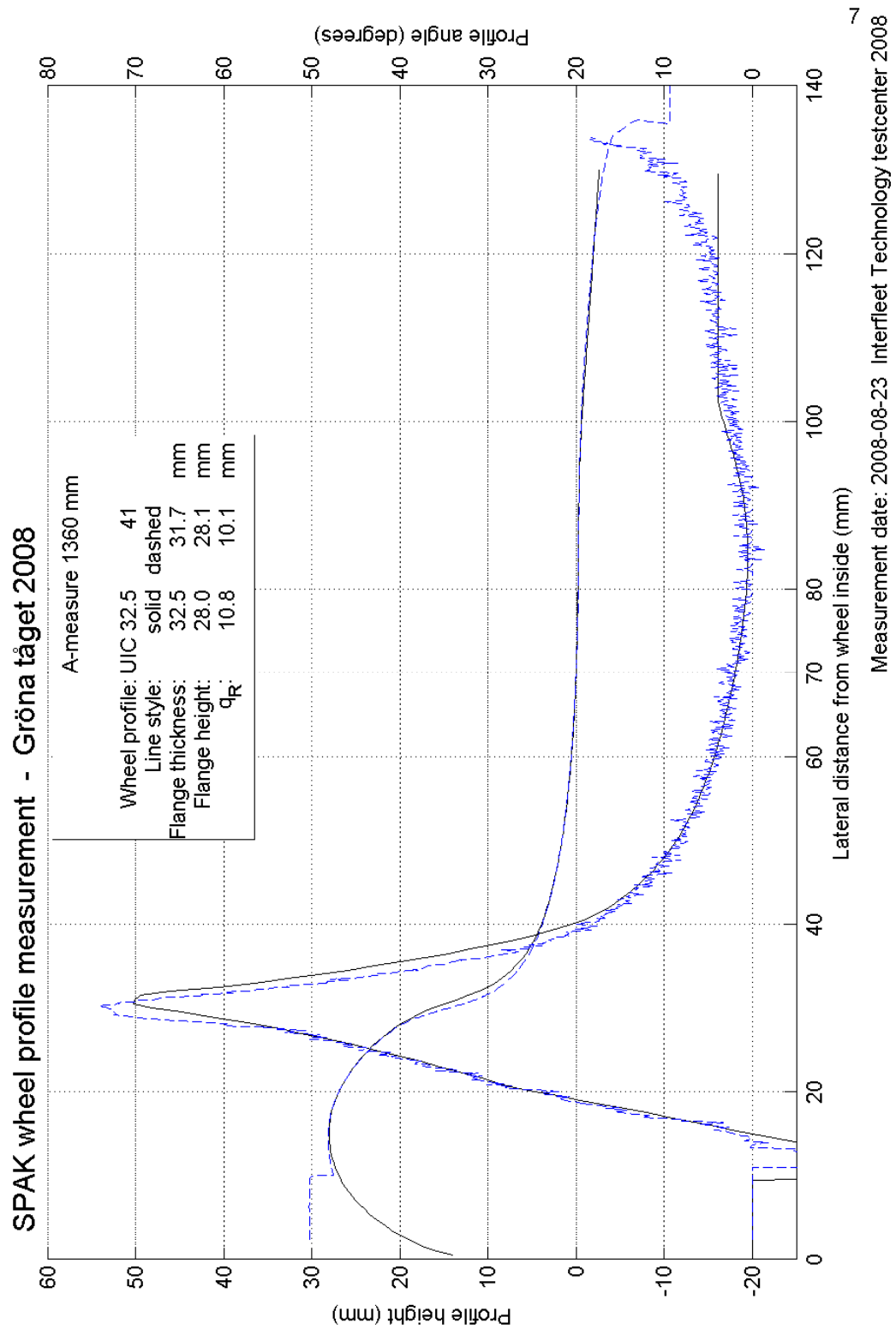


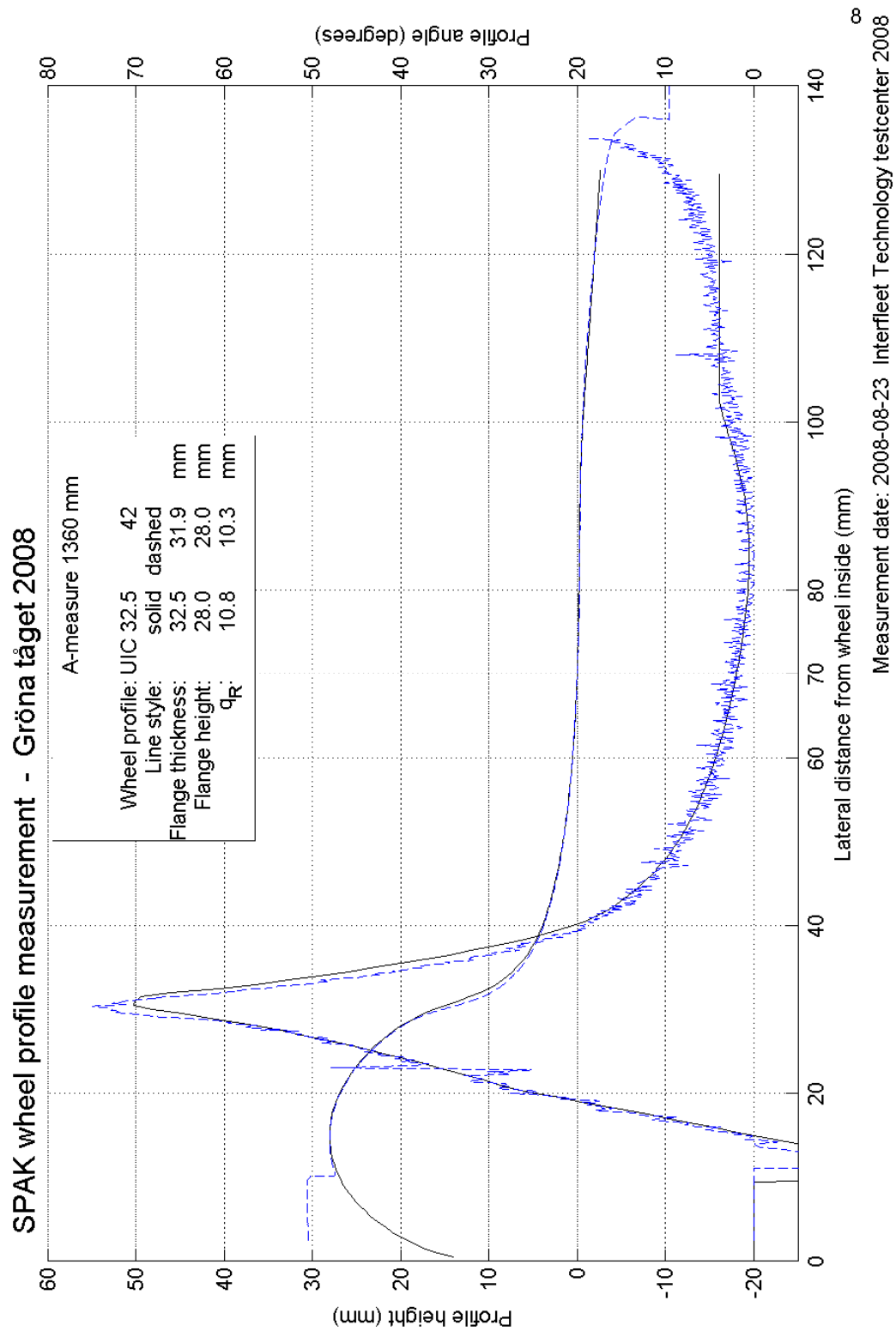


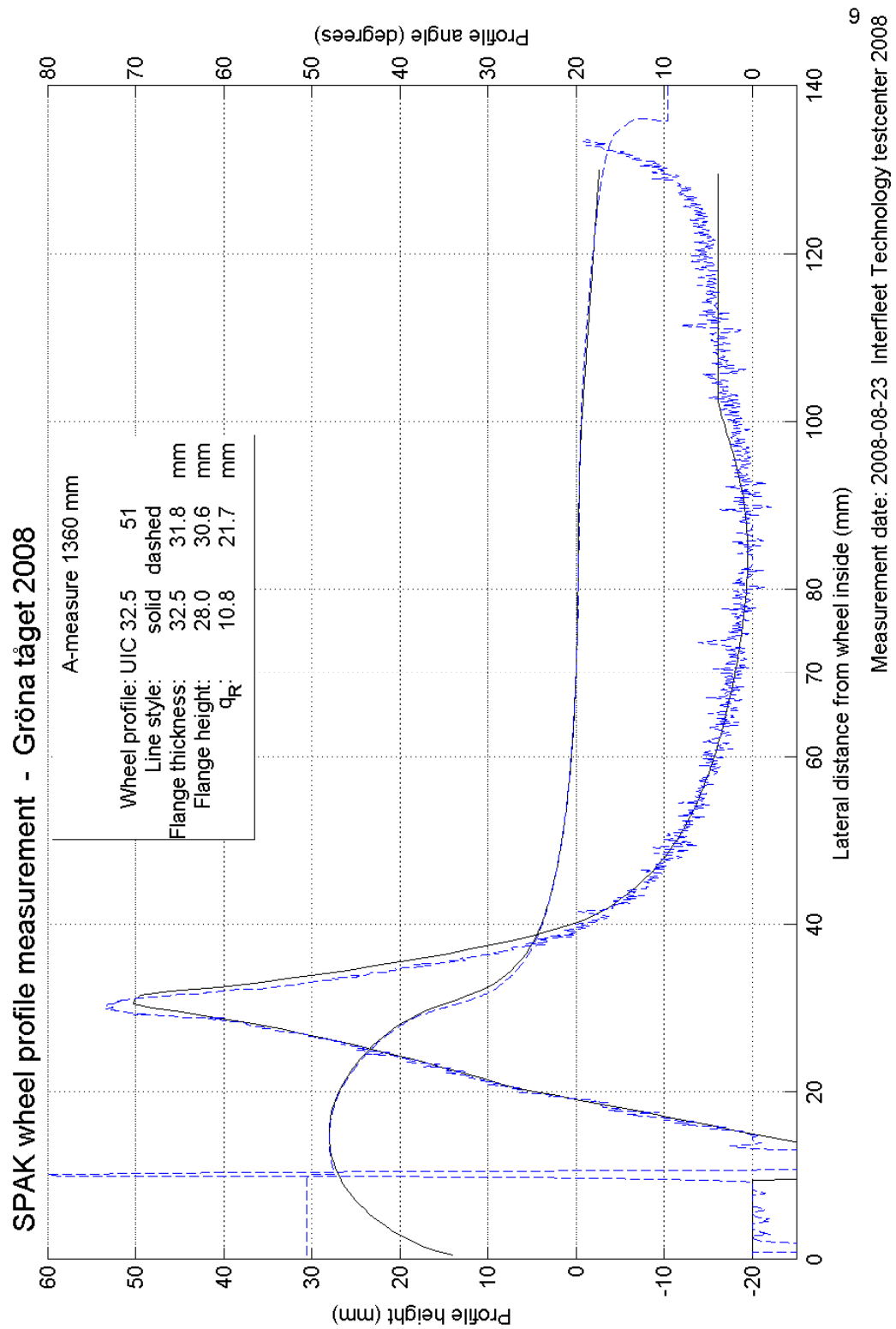


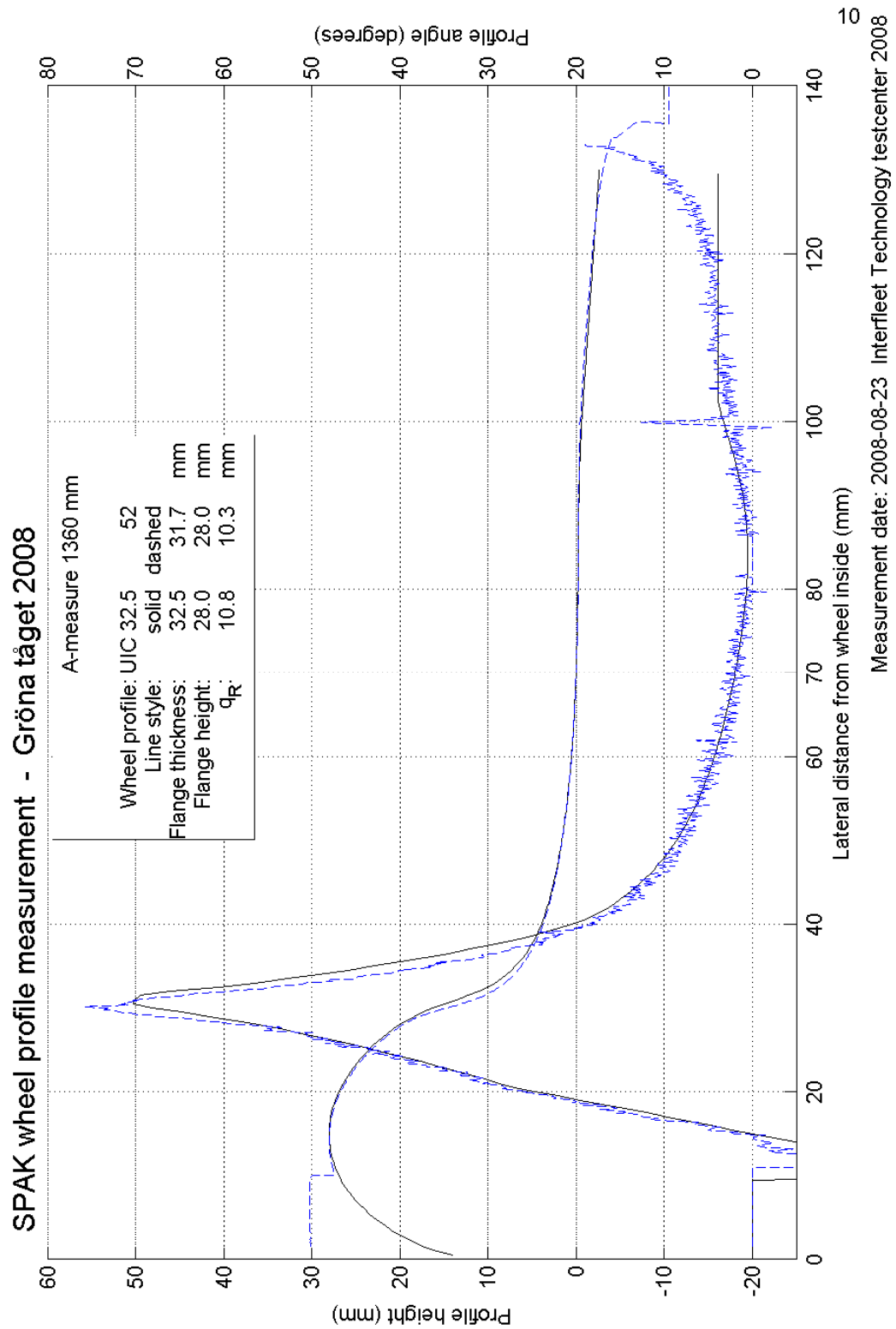


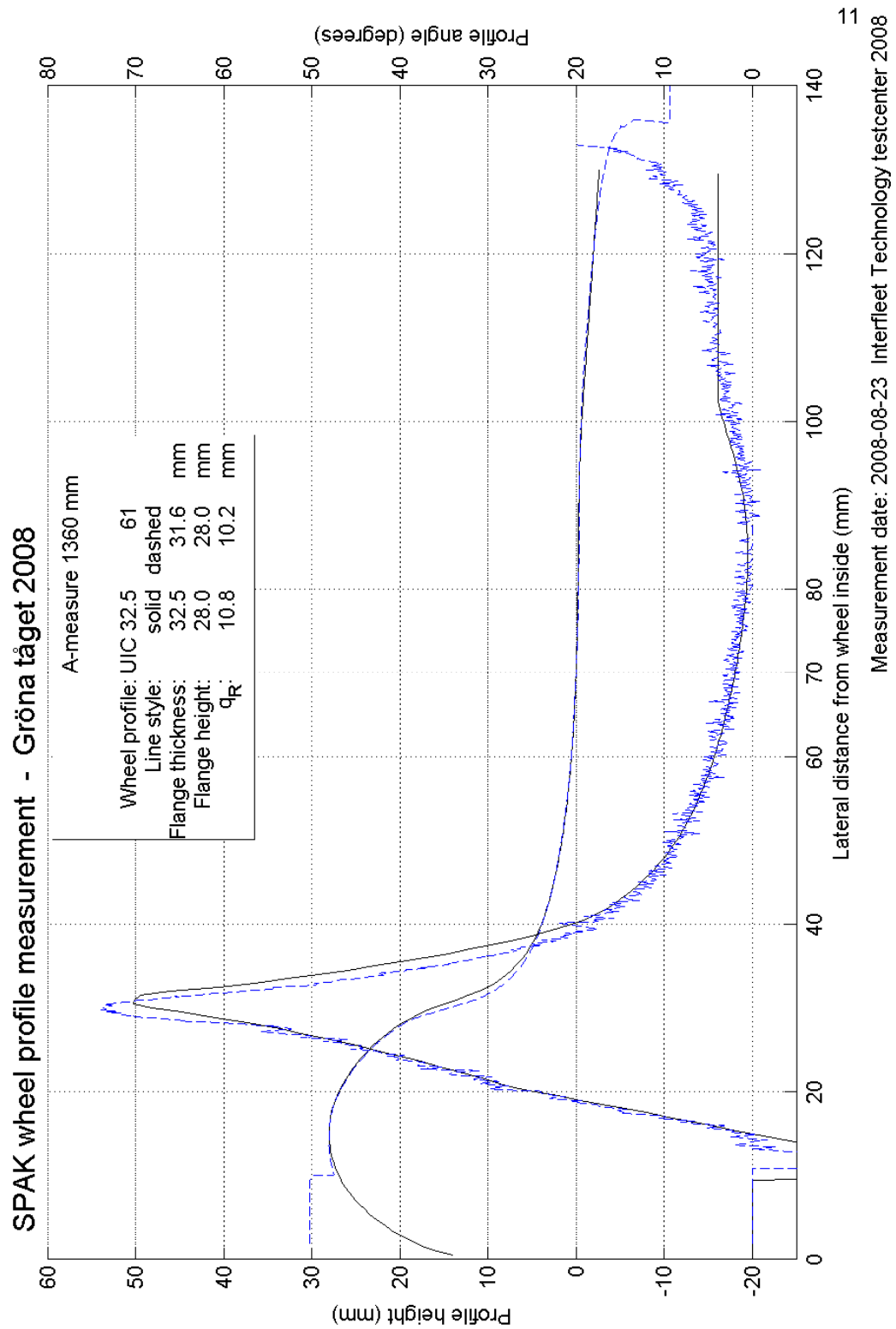


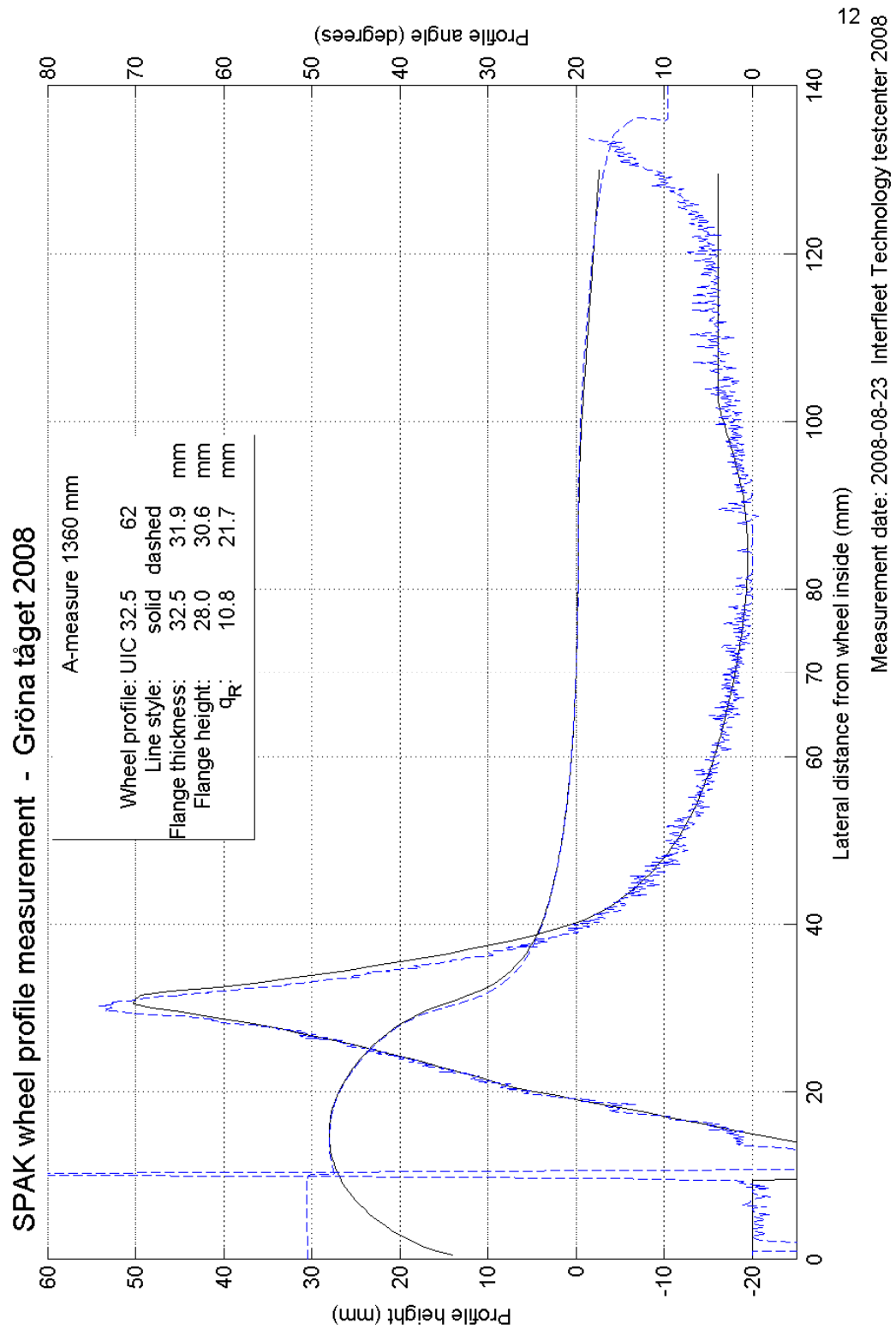


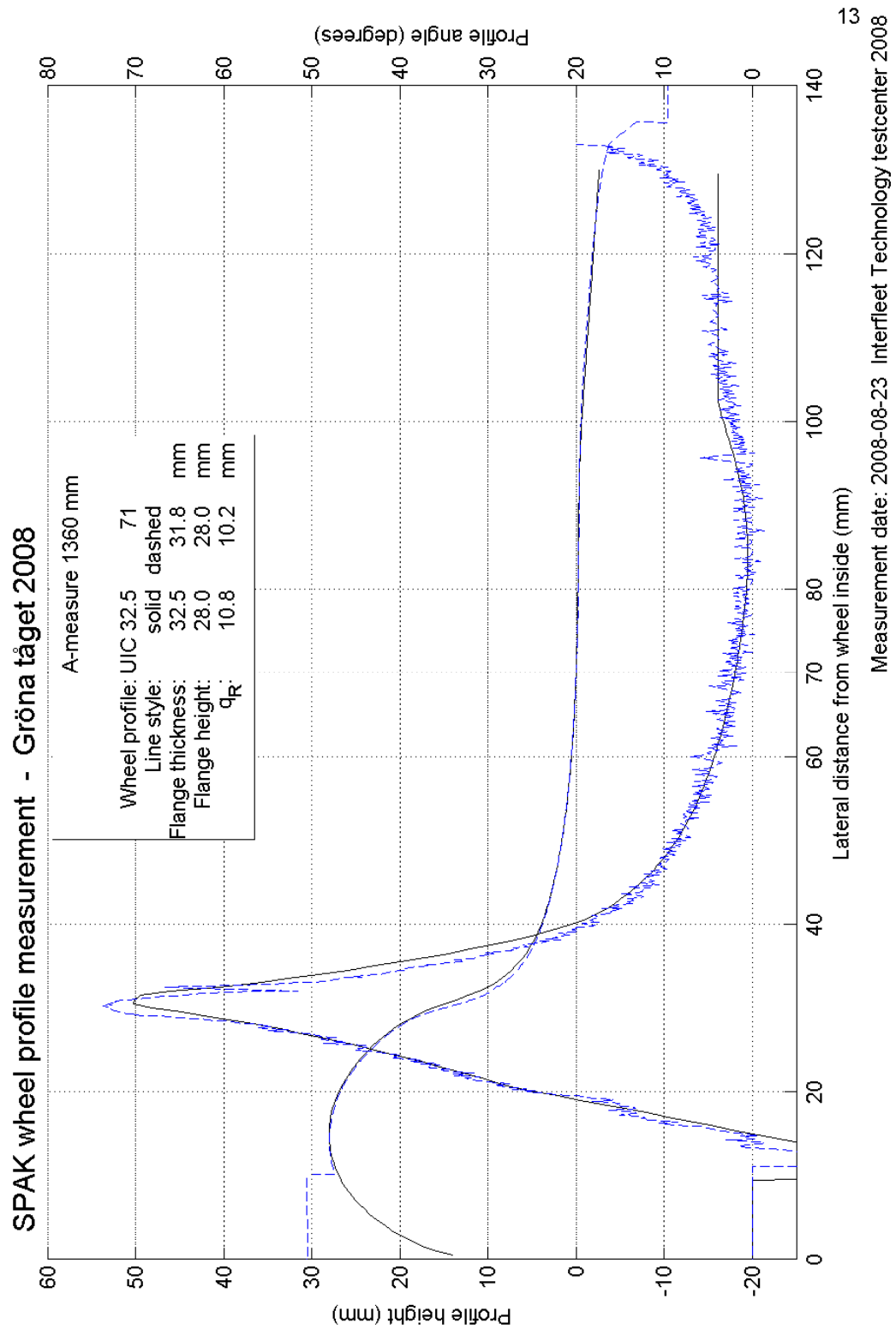


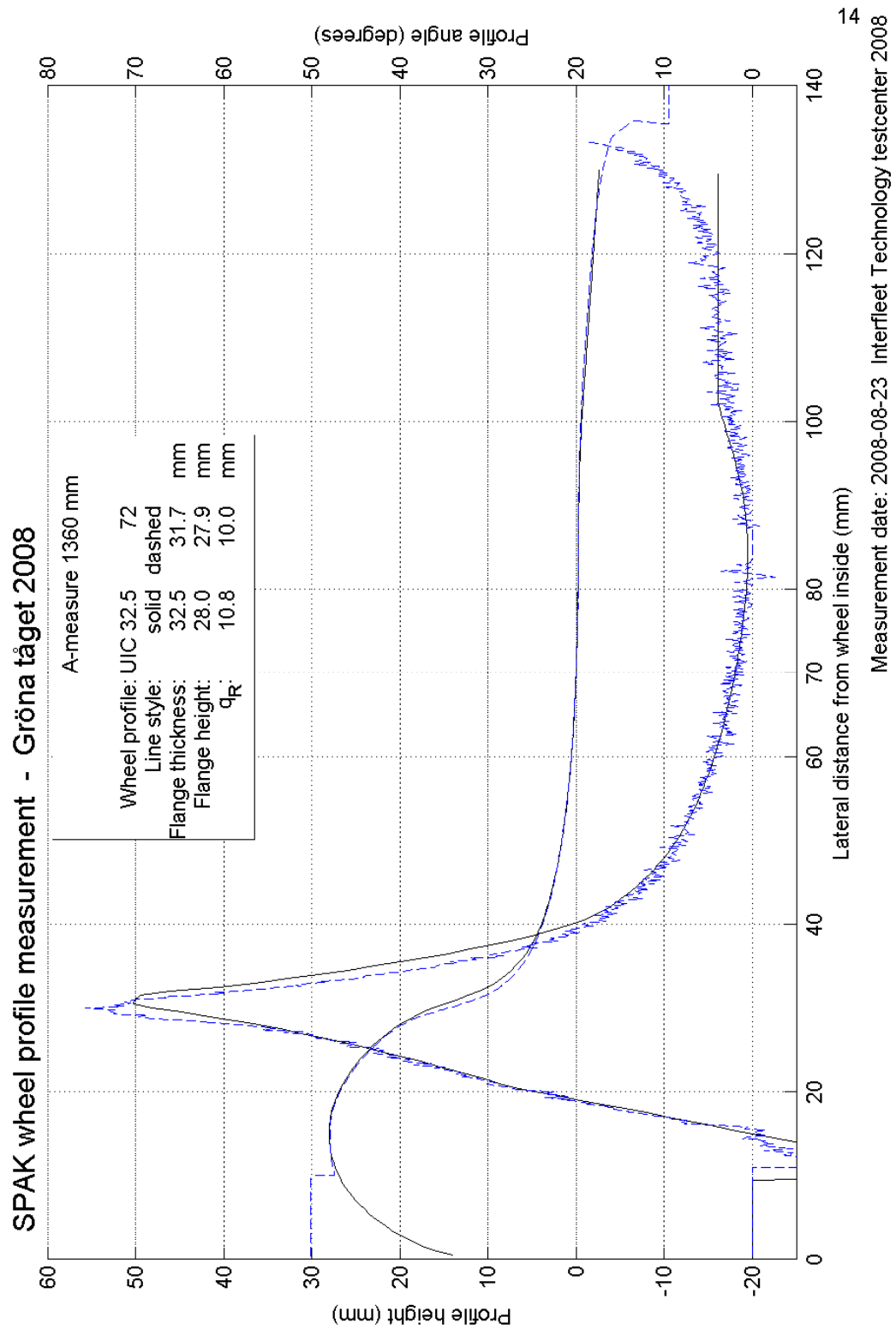


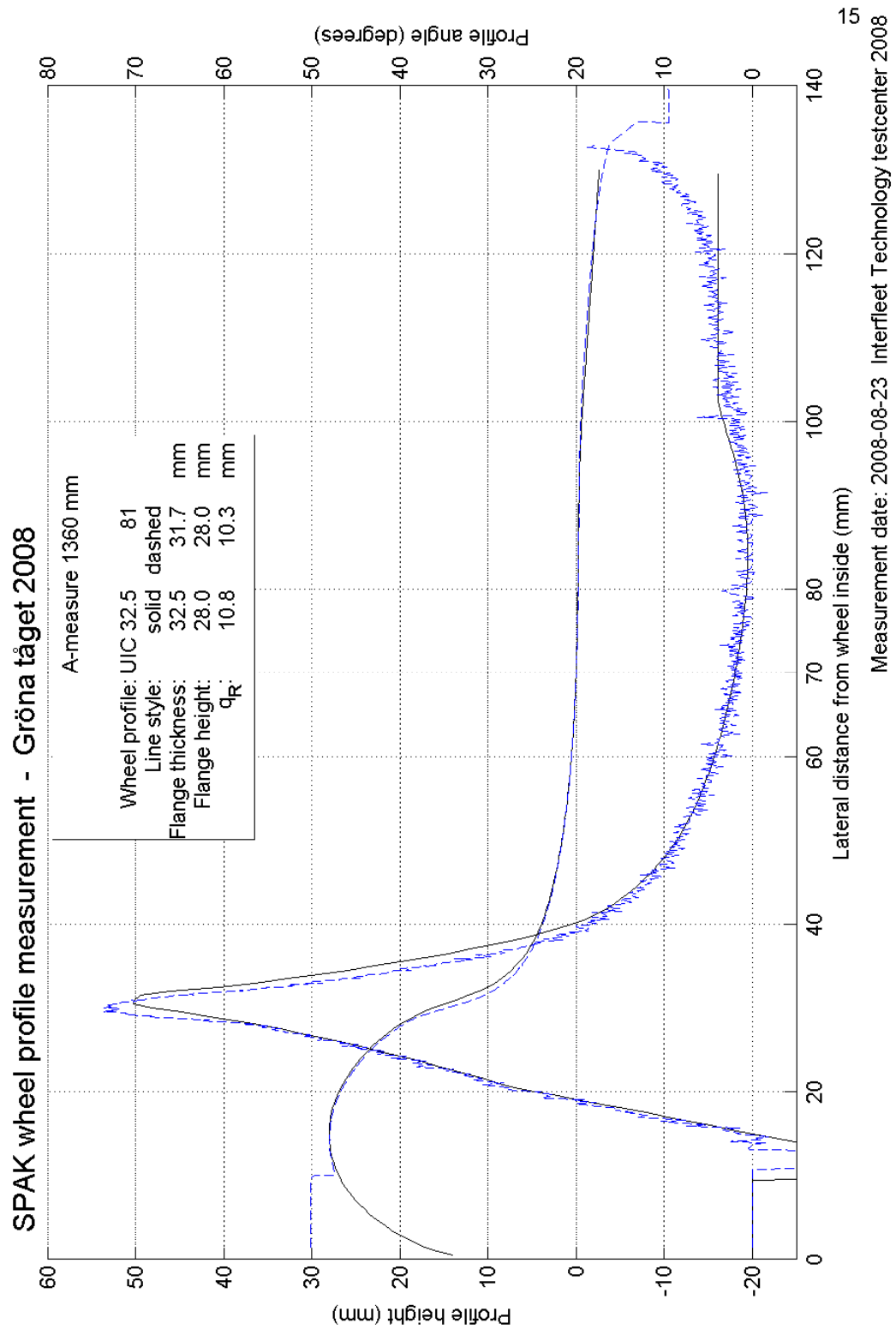


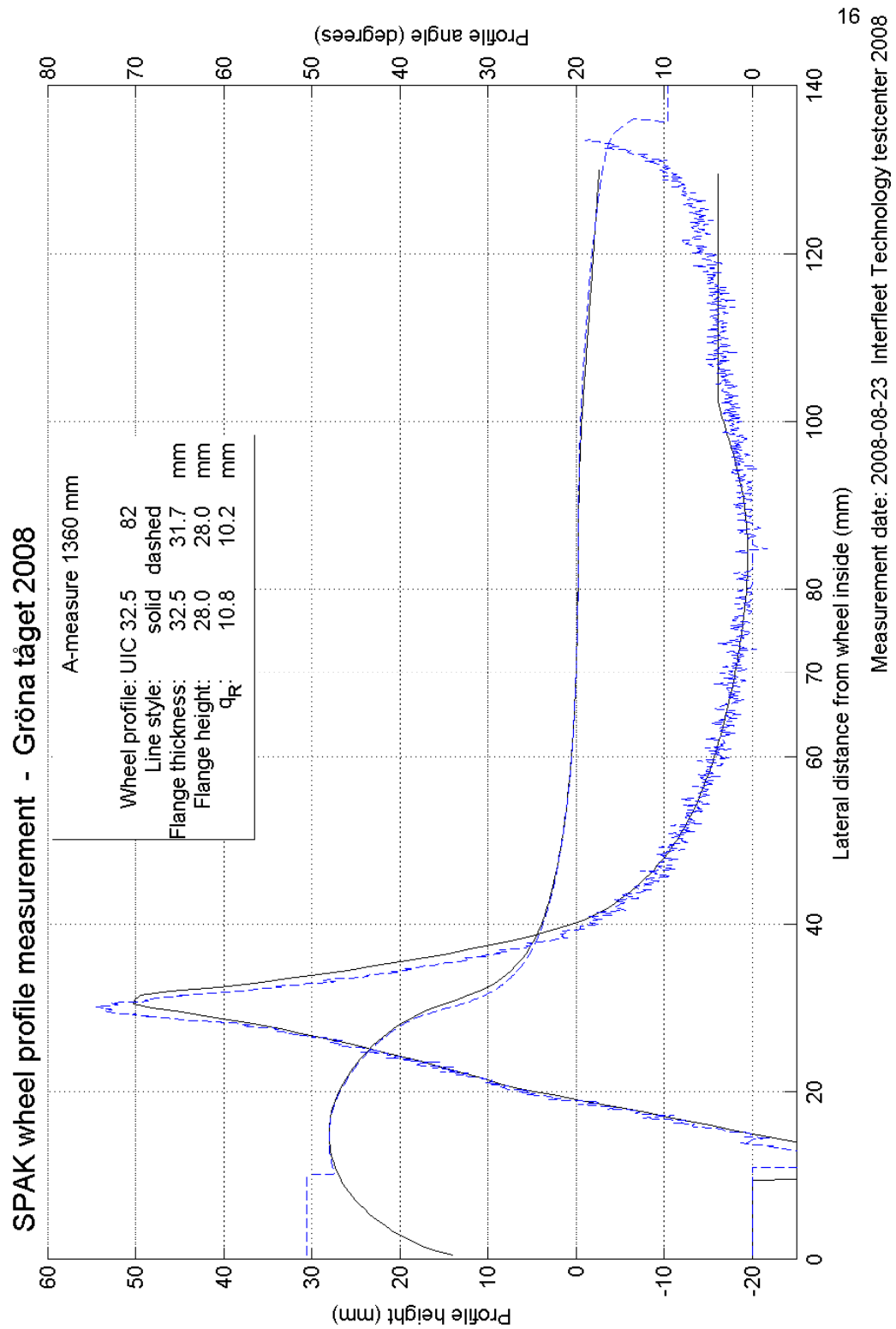




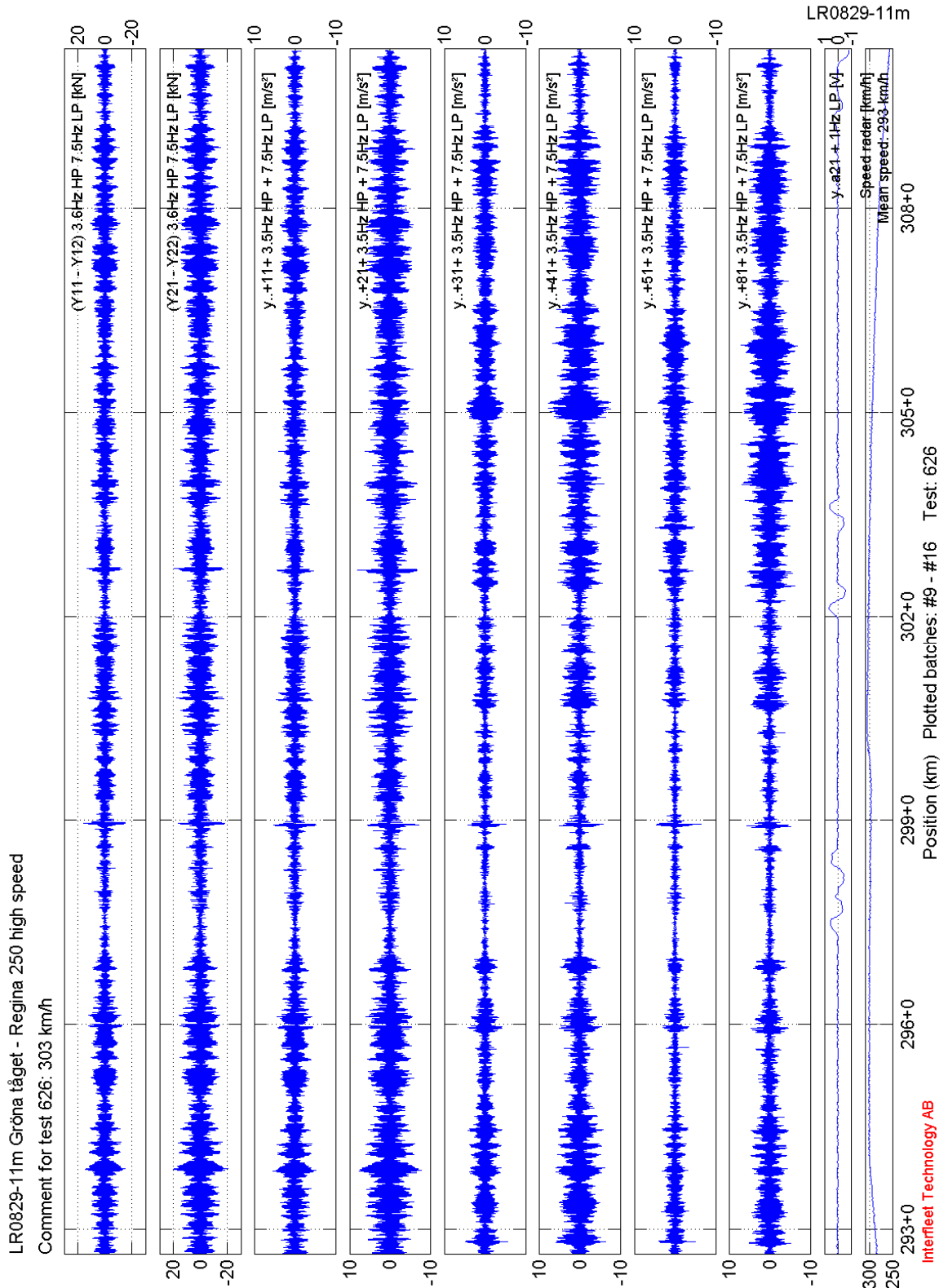


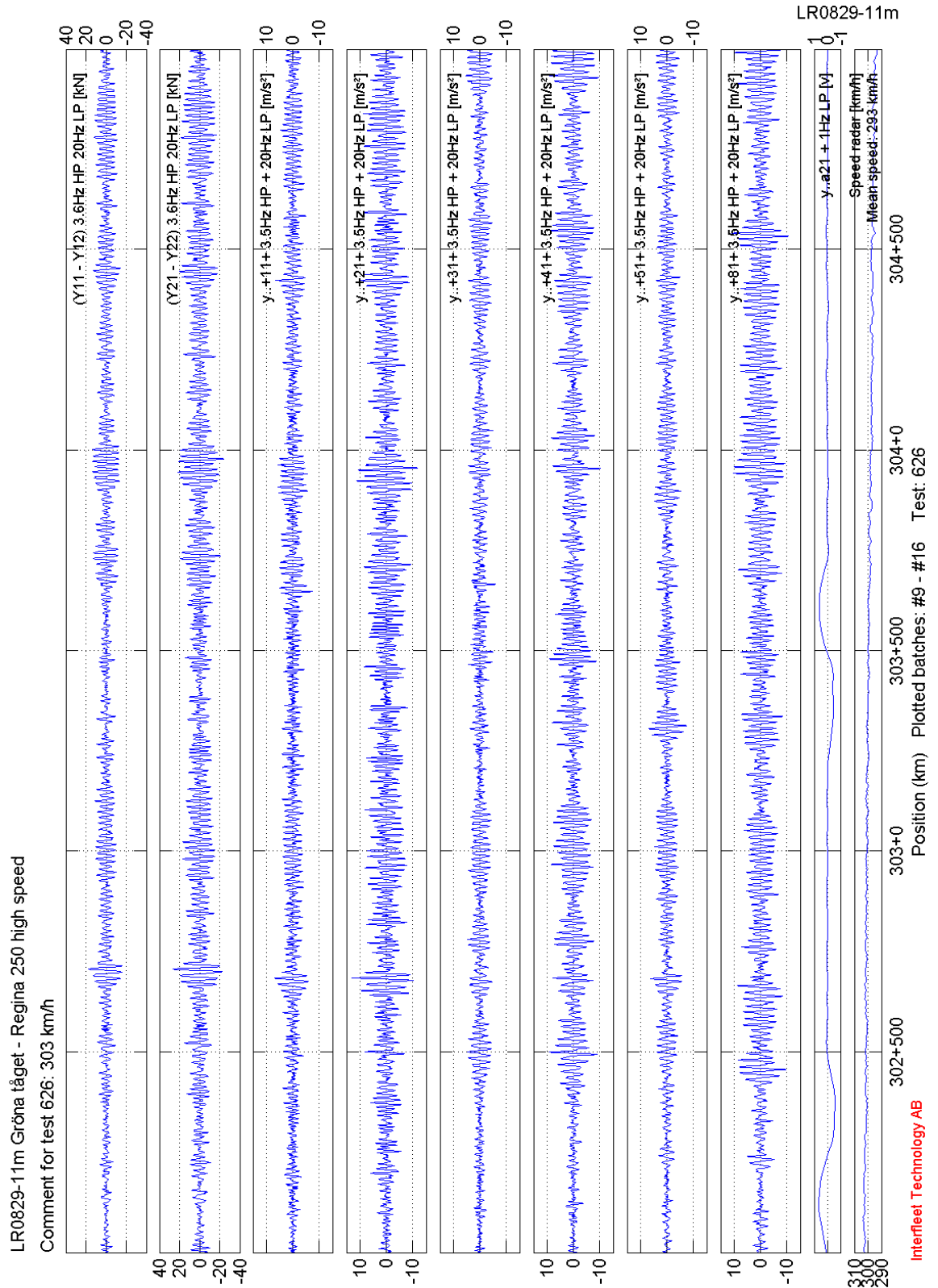


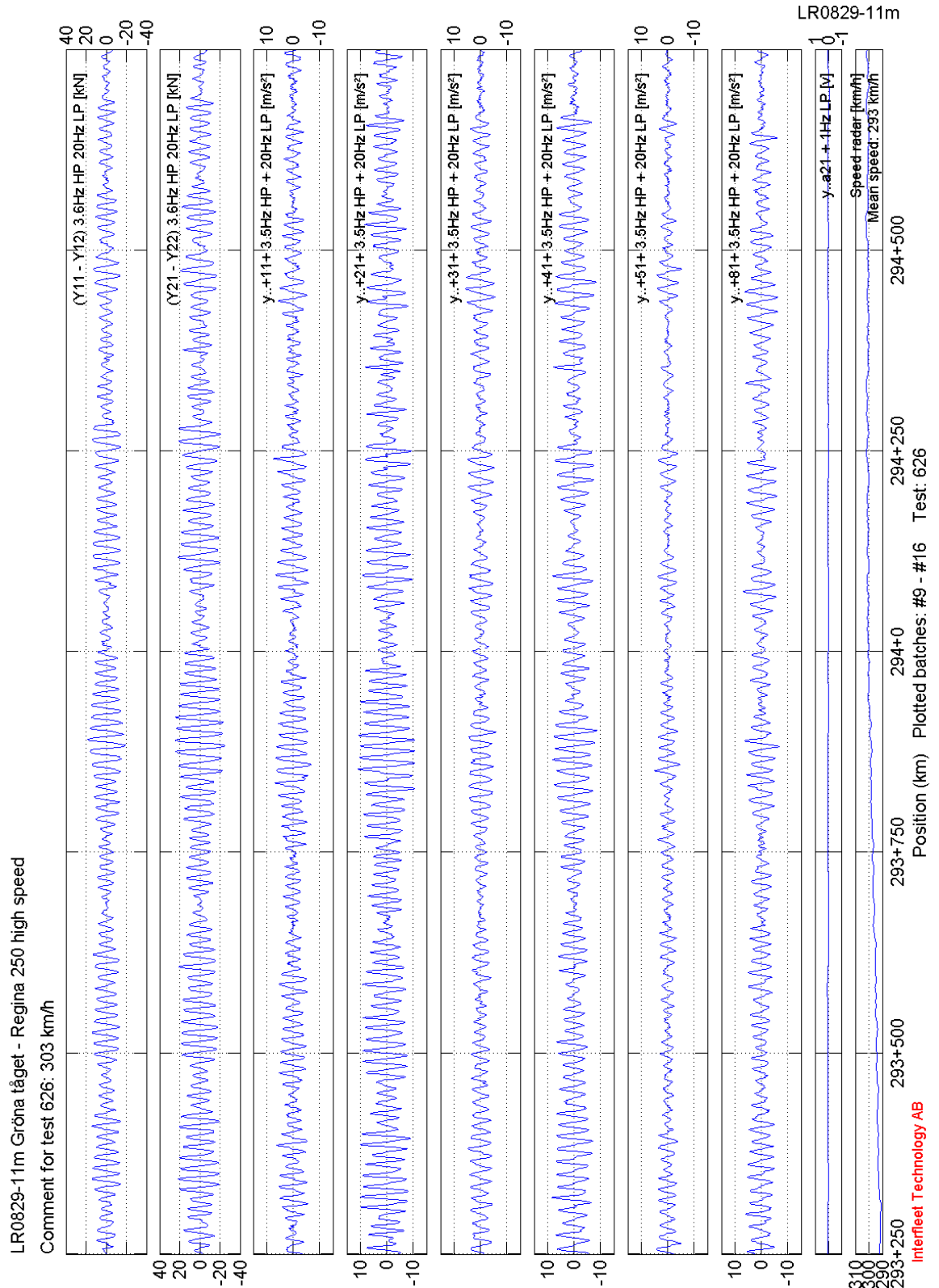


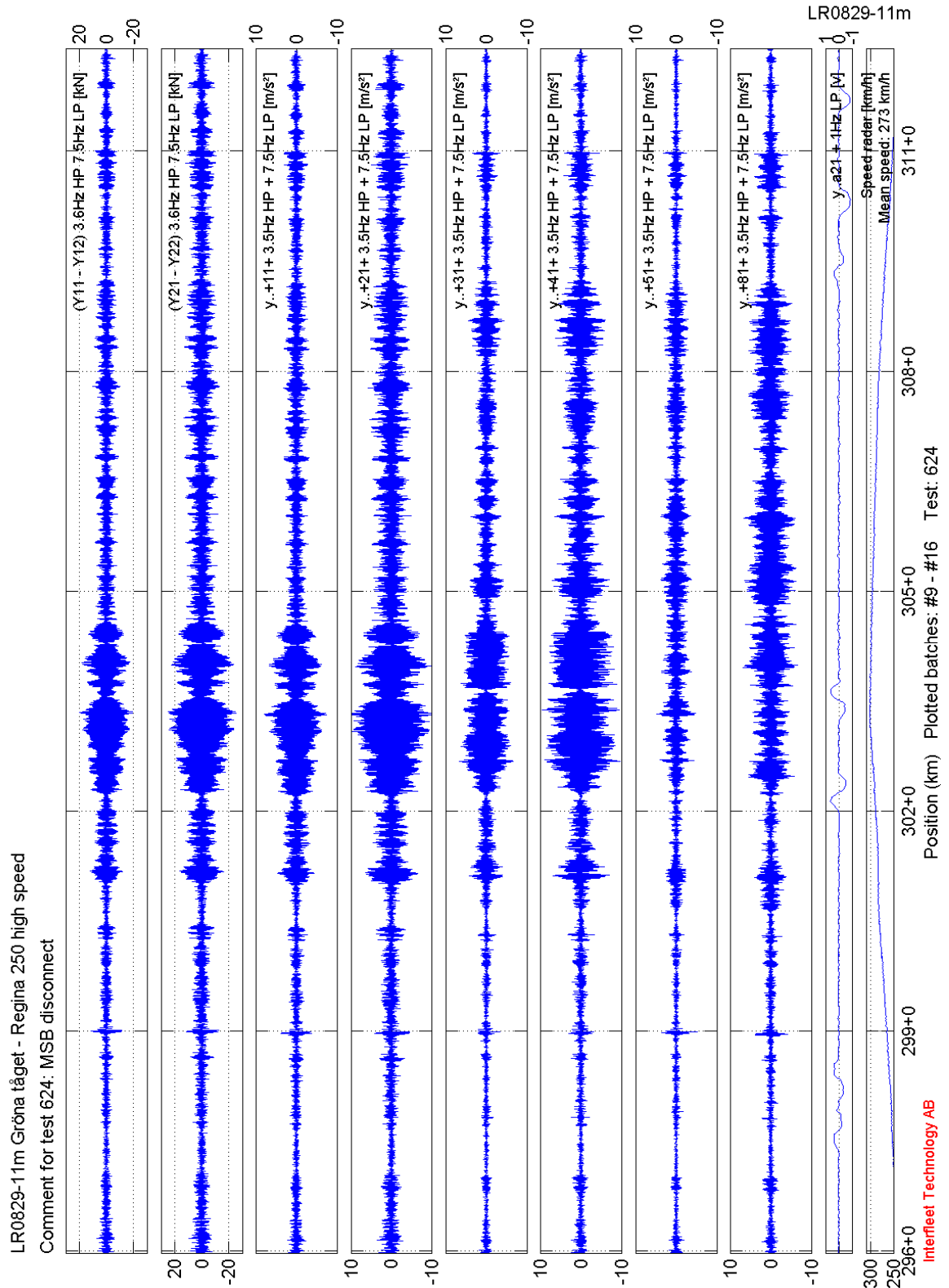


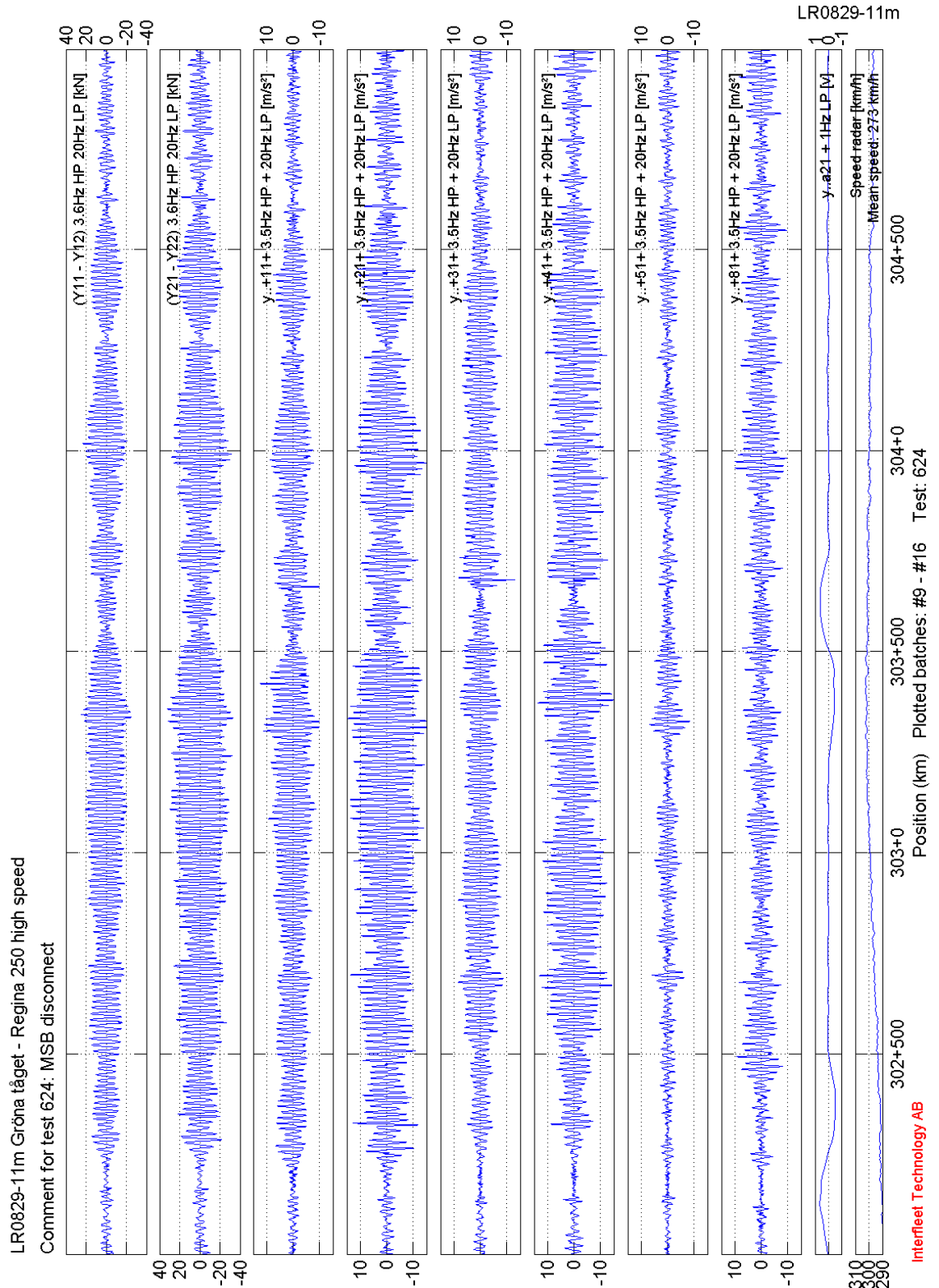
Appendix 20: High speed stability, details











Appendix 21: Q_{dyn} with 140 Hz bandwidth, high peaks time series

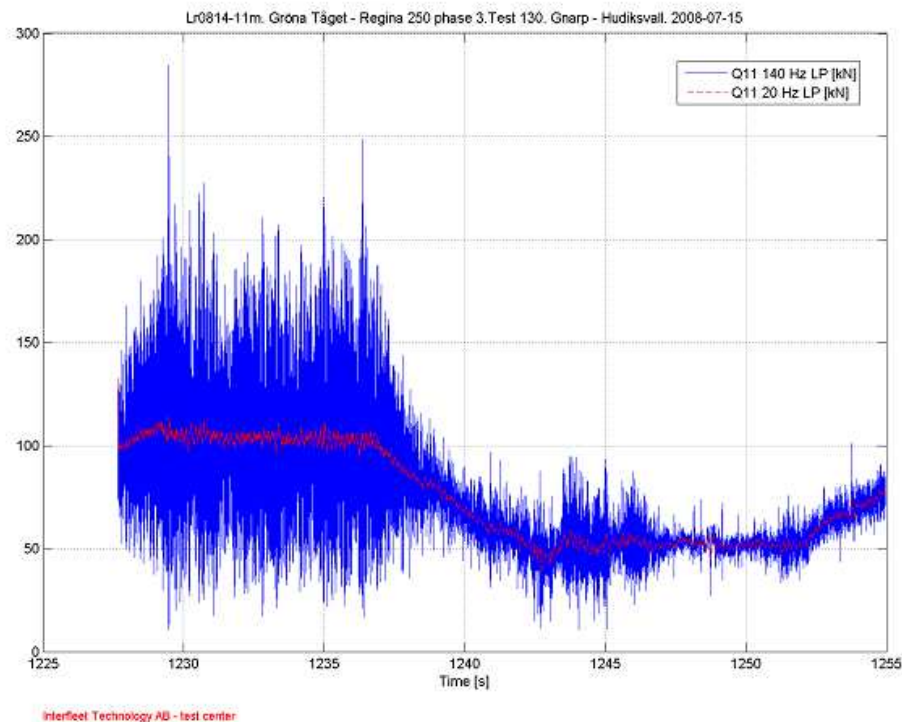


Figure 4 Effects on Q11-force of rail corrugation in 483 m curve at kmp 274+500m

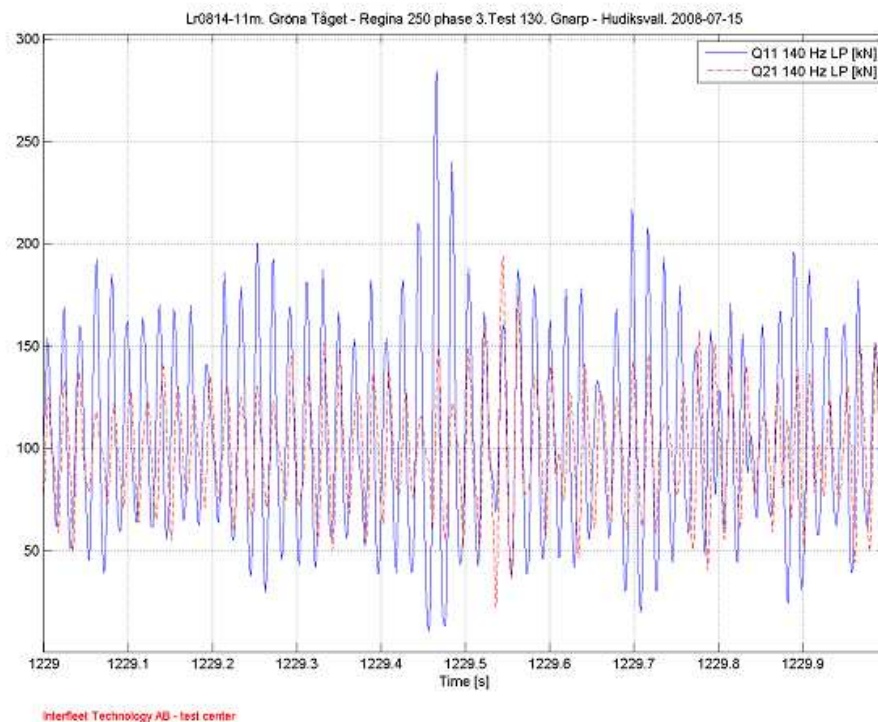


Figure 5 Details of Q11 and Q21 at kmp 274+500m

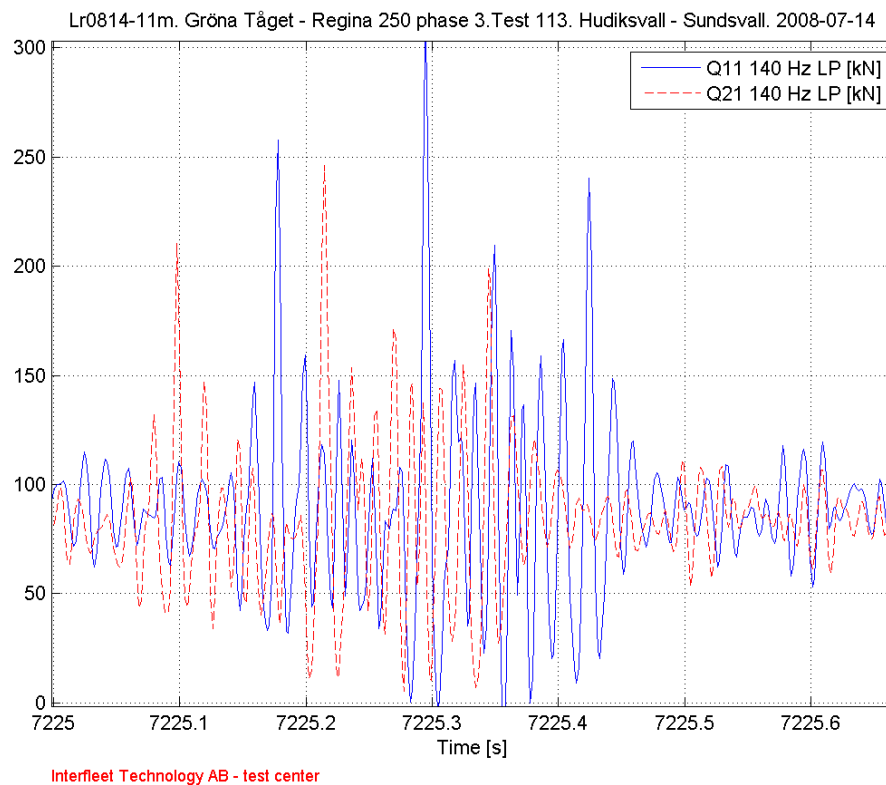


Figure 6 Singularities in 962 m curve at kmp 273+500m

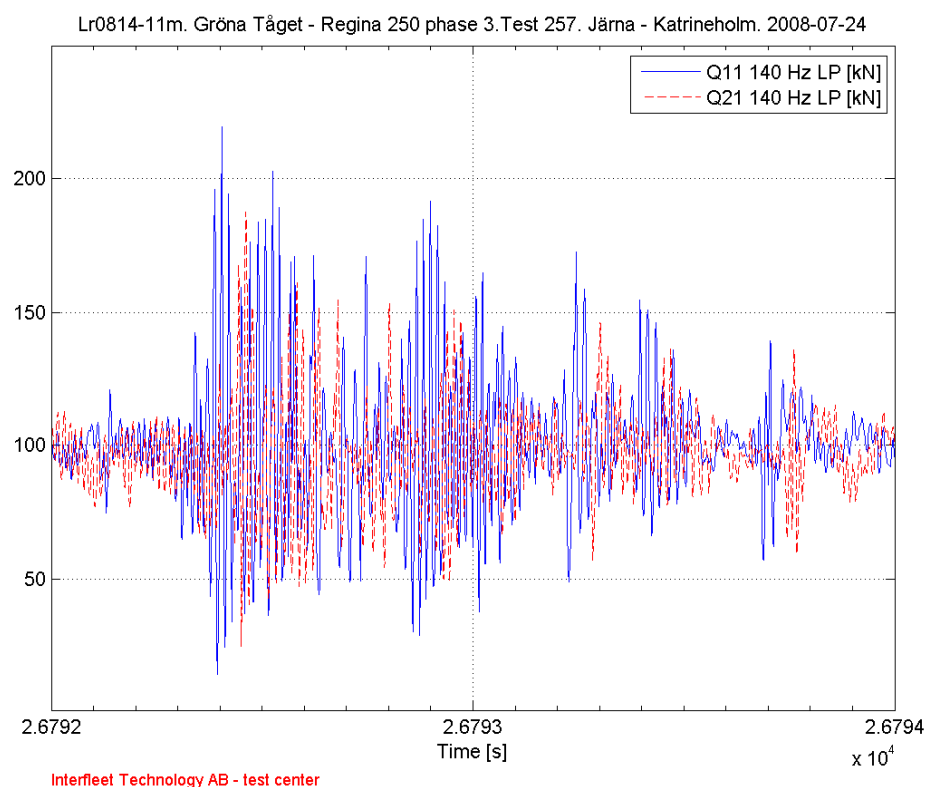


Figure 7 Switch in 1046 m curve at kmp 96+400m, Sparreholm station