

**DU3457**

**The Surface Durability of PEM  
MEGAGEARS®**

**Power Engineering and  
Manufacturing Ltd**

**1<sup>st</sup> December 2003**



**DESIGN UNIT**  
**GEAR TECHNOLOGY CENTRE**

University of Newcastle upon Tyne

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**TEST SUMMARY**

D.U. Project Ref : DU3457  
Client : Power Engineering and Manufacturing Ltd  
Client Contact : Mr. Saul Herscovici  
Client Reference : SH-1000  
Date : 1<sup>st</sup> December 2003

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## The Surface Durability of PEM MEGAGEARS® with Crowning and Tip Relief

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### 1. Introduction

Additional surface durability tests have been carried out on two pairs of MEGAGEARS® that were re-ground by Design Unit with 20µm lead crowning and 10µm parabolic tip relief on both left and right hand gears. The involute, lead and pitch traces and surface roughness measurements are shown in Annex 1.

The test conditions were as follows:

- Pinion torque : 4000 / 4500Nm
- Pinion speed : 3000rpm
- Lubricant : 100 cSt Mineral Oil + 4% Anglamol
- Lubricant temperature : 70°C
- Lubricant flow rate : 34l / min
- Lubricant tank volume : 70l
- Lubrication filtration : 20µm full flow

The gears were deemed to have failed when the area of macro-pitting was greater than or equal to 4% of one tooth flank or 1% of all flanks. The gears were to be run for a total

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of  $50 \times 10^6$  load cycles (280 hours) at each torque level unless the failure limit was exceeded at any stage.

## 2. Test Results

The results for tests run at torques of 4000 and 4500Nm are summarised in Table 2.1. Photographs of the failures that occurred on the pinion and wheel flanks of MEGAGEAR® G-B13210-3 are shown in Figures 2.1 – 2.3.

**Table 2.1:** Summary of additional surface durability test results.

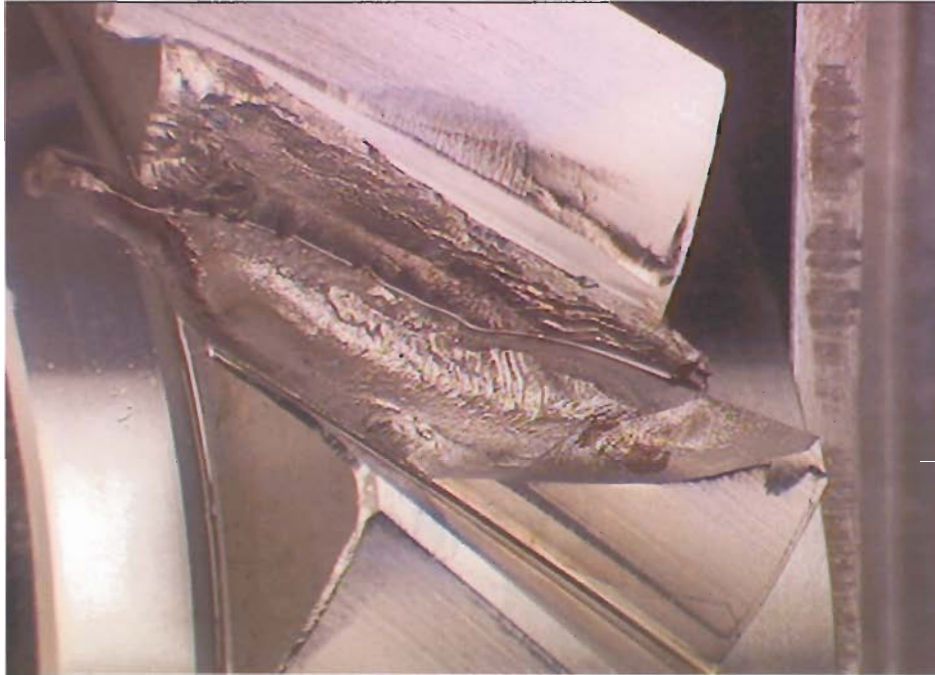
Test No.	Gear Number	Test Torque (Nm)	Test Flank	No. of Cycles ( $\times 10^6$ )	Failure Mode
1	G-B13210-3 (Box A)	4500	Wheel (Right flank)	5.77	Edge cracks across face on 2 teeth (secondary pitting damage on 1 tooth), edge cracks on 14 other teeth
	G-B13211-3 (Box A)	4500	Pinion (Right flank)	5.77	No surface failure, edge cracks on 12 teeth
	G-B13210-4 (Box B)	4500	Wheel (Right flank)	5.77	No surface failure, no edge cracks
	G-B13211-4 (Box B)	4500	Pinion (Right flank)	5.77	No surface failure, edge cracks on 4 teeth
2	G-B13210-3 (Box A)	4000	Pinion (Left flank)	8.09	Edge crack across root on 1 tooth resulting in partial detachment of tooth cracked and pitted at 4500Nm, edge cracks on 8 other teeth
	G-B13211-3 (Box A)	4000	Wheel (Left flank)	8.09	No surface failure, edge cracks on 3 teeth
	G-B13210-4 (Box B)	4000	Pinion (Left flank)	8.09	No surface failure, edge cracks on 5 teeth
	G-B13211-4 (Box B)	4000	Wheel (Left flank)	8.09	No surface failure, edge cracks on 9 teeth



**Figure 2.1:** Edge cracking and secondary pitting damage on wheel flank of MEGAGEAR® G-B13210-3 after  $5.77 \times 10^6$  cycles (4500Nm, 100 cSt Mineral Oil + 4% Anglamol, 70°C, 3000rpm).



**Figure 2.2:** Edge cracking across face on wheel flank of MEGAGEAR® G-B13210-3 after  $5.77 \times 10^6$  cycles (4500Nm, 100 cSt Mineral Oil + 4% Anglamol, 70°C, 3000rpm).



**Figure 2.3:** Edge cracking along root of wheel flank on MEGAGEAR® G-B13210-3 after  $5.77 \times 10^6$  cycles (4000Nm, 100 cSt Mineral Oil + 4% Anglamol, 70°C, 3000rpm) – likely to be consequential damage resulting from an existing crack on opposite flank initiated during Test No. 1.

## **ANNEX 1**

### **PROFILE, LEAD AND PITCH TRACES**

### **SURFACE ROUGHNESS MEASUREMENTS**



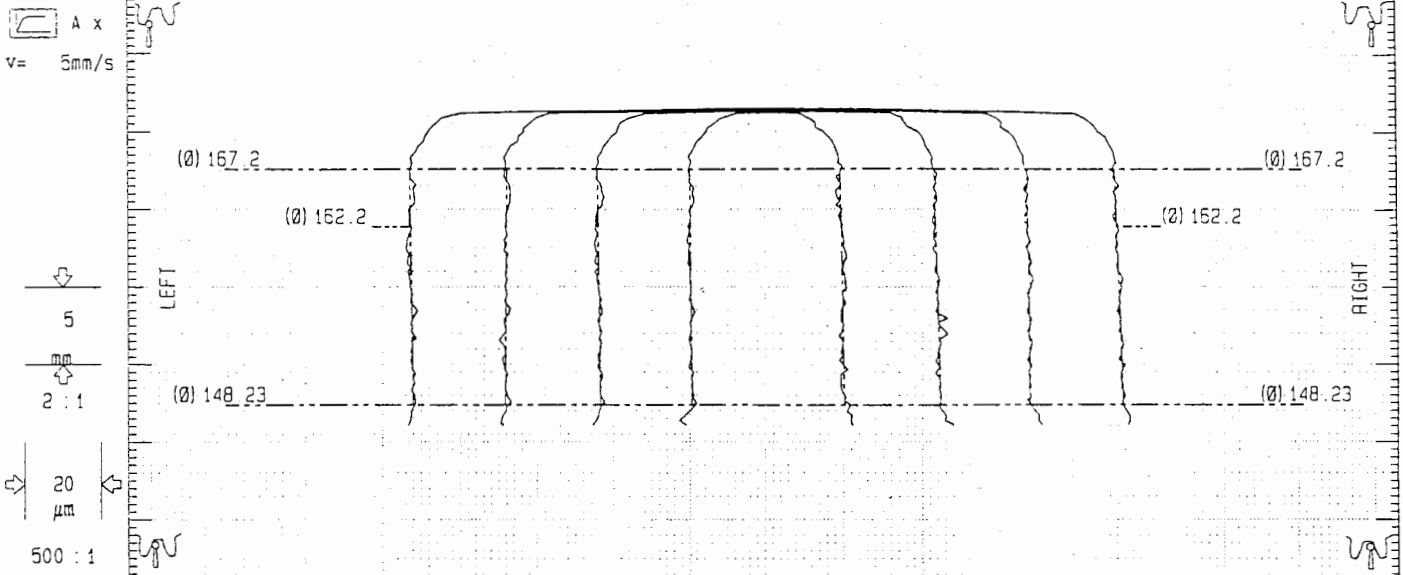
REMARKS R

NGML

DIN 3961/62 / (mm)

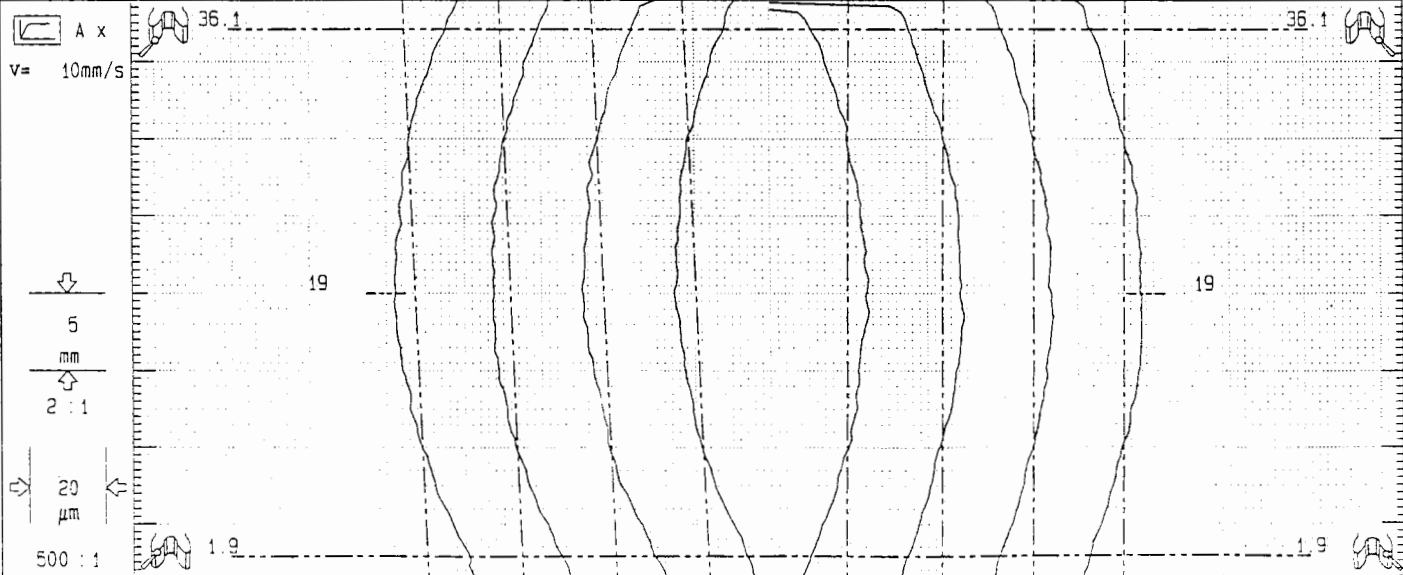
SPUR/HELICAL GEAR

z	19 R/R	$\alpha_n$	25° 0' 0"	$\phi$	2mm	$D_0$	139.315/139.315 mm
$m_n$	6.35 mm	$\beta$	30° 0' 0"/30° 0' 0"	b	38 mm	$d_b$	122.663/122.663 mm
NDP	4/inch	$\beta_b$	26° 56' 46"/26° 56' 46"	x	2.008	$L\beta$	90->90/90->90 %



SQ	[...]	$\bar{x}$	Q	16	11	6	1	1	6	11	16	Q	$\bar{x}$	[...]	
FS	0/12	2.8	2	2.8	3.2	2.6	2.4	$F_{\alpha}$	3.5	3.9	2.6	3.2	2	3.3	0/12
	0/10	2.8	2	2.8	3.4	2.8	2.2	$F_{\epsilon\alpha}$	2.8	3.2	2.3	1.9	2	2.6	0/10
	+/-7	2	1	6	-6	6	3	$F_{H\alpha}$	-9	-1.5	-9	-2.0	2	-1.3	+/-7
	-/-	2						$F_{H\alpha M}$					-1.3	-/-	
	-/-	1.2						$F_{\sigma\alpha}$					1.1	-/-	

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SQ	[...]	$\bar{x}$	Q	16	11	6	1	1	6	11	16	Q	$\bar{x}$	[...]	
FS	0/8	18.5	8	18.9	17.8	18.6	18.7	$F_{\beta}$	15	15	15	14.2	7	14.8	0/8
	0/6	16	9	16.3	15.2	16	16.4	$F_{\epsilon\beta}$	15	14.6	14.5	14	9	14.5	0/6
	+/-6.5	-5.5	5	-5.5	-3.1	-3.6	-5.9	$F_{H\beta}$	1.2	1.3	1.1	1.2	1	1.2	+/-6.5
	-/-	-5.5						$F_{H\beta M}$					1.2	-/-	
	-/-	8						$F_{\sigma\beta}$					2	-/-	

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DIN 3961/62 / (mm)

UNIVERSITY OF NEWCASTLE

PITCH

MEGA RIGHT MID././ N°3

SERIAL NO 4



REMARKS R

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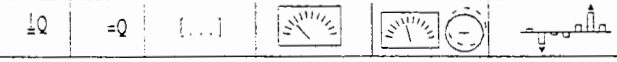
z 19 R/R  $\alpha_n$  25° 0' 0"  $\phi$  2mm Do 139.315/139.315 mm

m<sub>n</sub> 6.35 mm B 30° 0' 0" / 30° 0' 0" b 38 mm db 122.663/122.663 mm  $\frac{z}{d}$

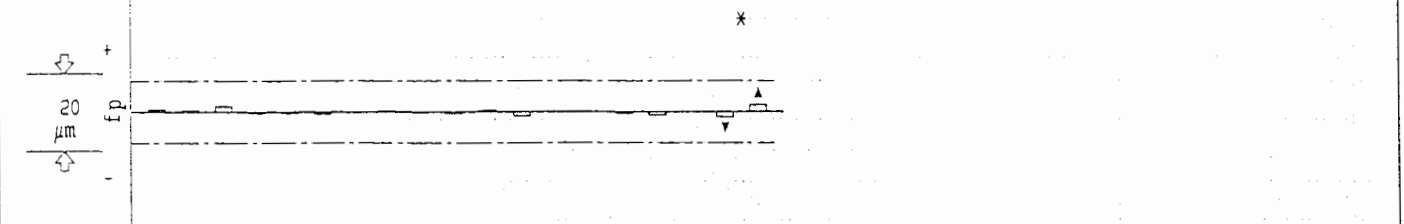
NDP 4/inch Bb 25° 55' 46" / 25° 56' 46" x 2.008 LB 90->90/90->90 %  $\frac{z}{d}$

v<sub>m</sub>= 10mm/s

v<sub>p</sub>= 15mm/s



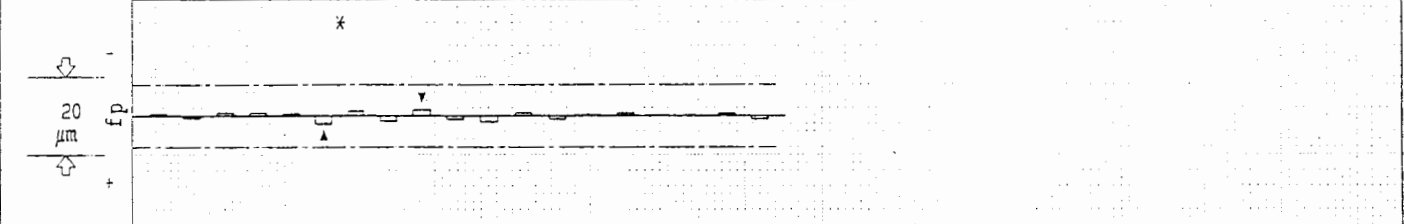
SPUR/HELICAL GEAR



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Fu	5	3	0/ 10	3.1		#19

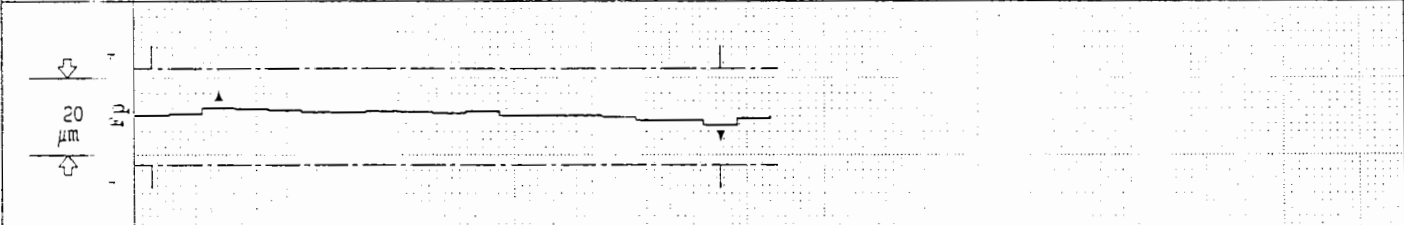
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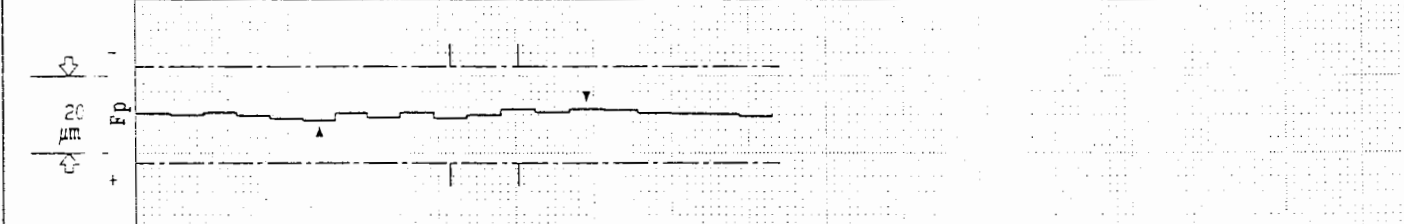
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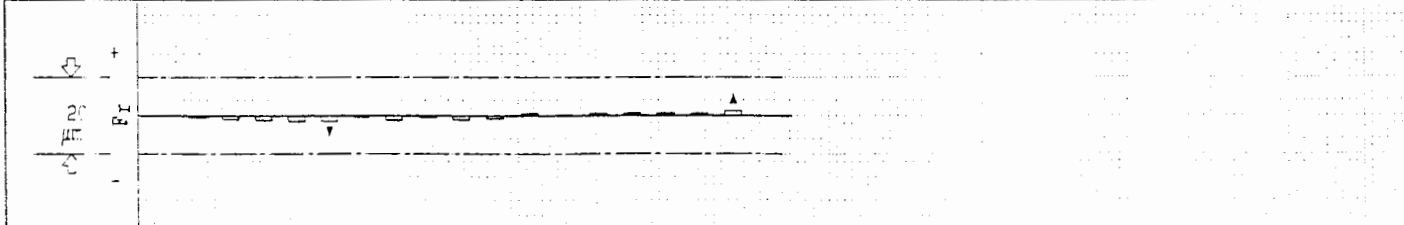


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Fz/8	5	1	0/ 16	2.5		

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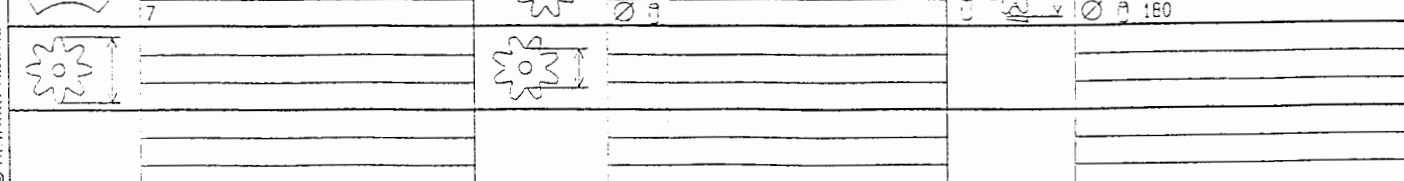
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Fz	5	1	0/ 20	2.7	#6	#18
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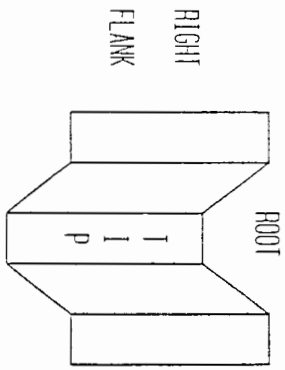
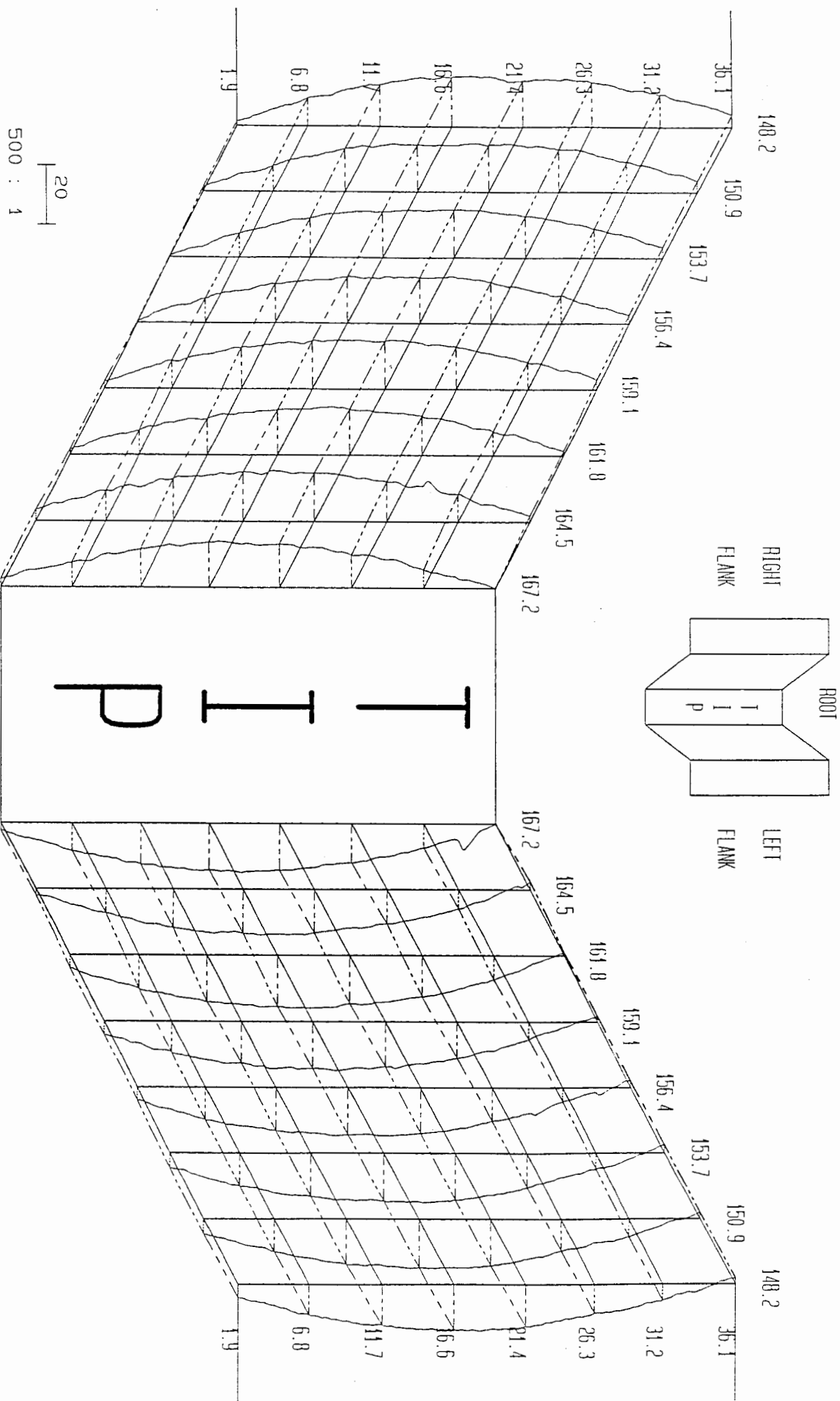
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<= 21.446 <=	<= 96.336 <=	<= 192.075 <=

132.049 <= 132.049 <= 132.049	Ø 18	Ø 18
<= 132.785 <=		<= 560.396 <=



ROOT

ROOT



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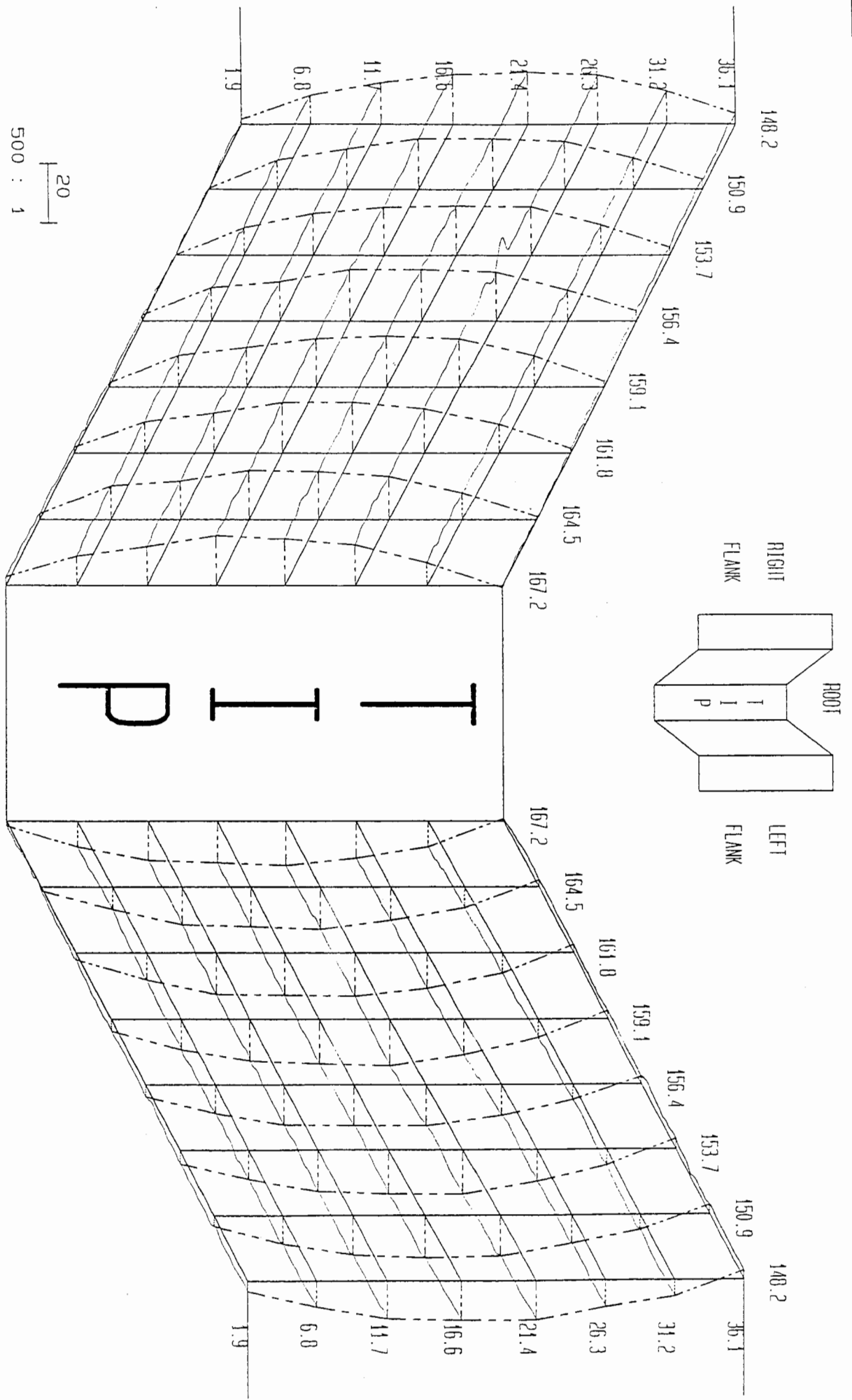
Klingenberg  
Soehne GmbH

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Klingelberg  
Soehne GmbH

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DIN 3961/62 / (mm)

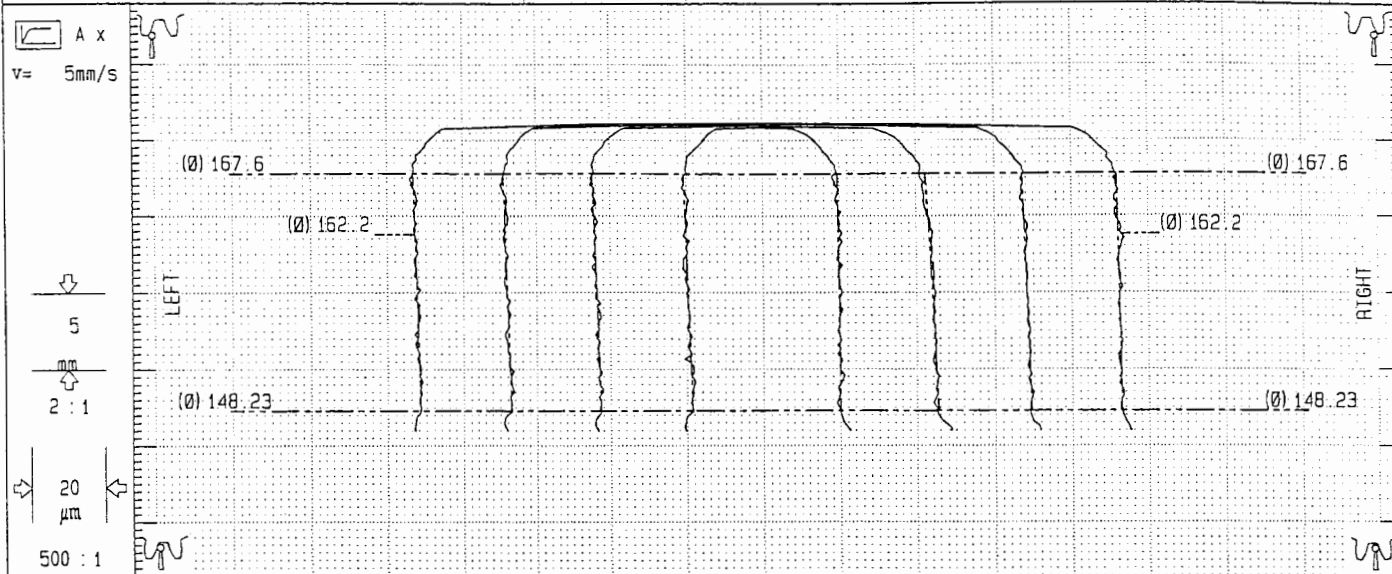


REMARKS \*

NGML

z	19	L/L	$\alpha_n$	25° 0' 0"	$\phi$	Ø 2mm					D0	139.315/139.315 mm	
$m_n$	6.35 mm	$\beta$		30° 0' 0" / 30° 0' 0"	b	38 mm	$d_b$	122.663/122.663 mm	*				
NDP	4/inch	$\beta_b$		25° 56' 46" / 25° 56' 46"	x	2.008	$L\beta$	90->90/90->90 %					

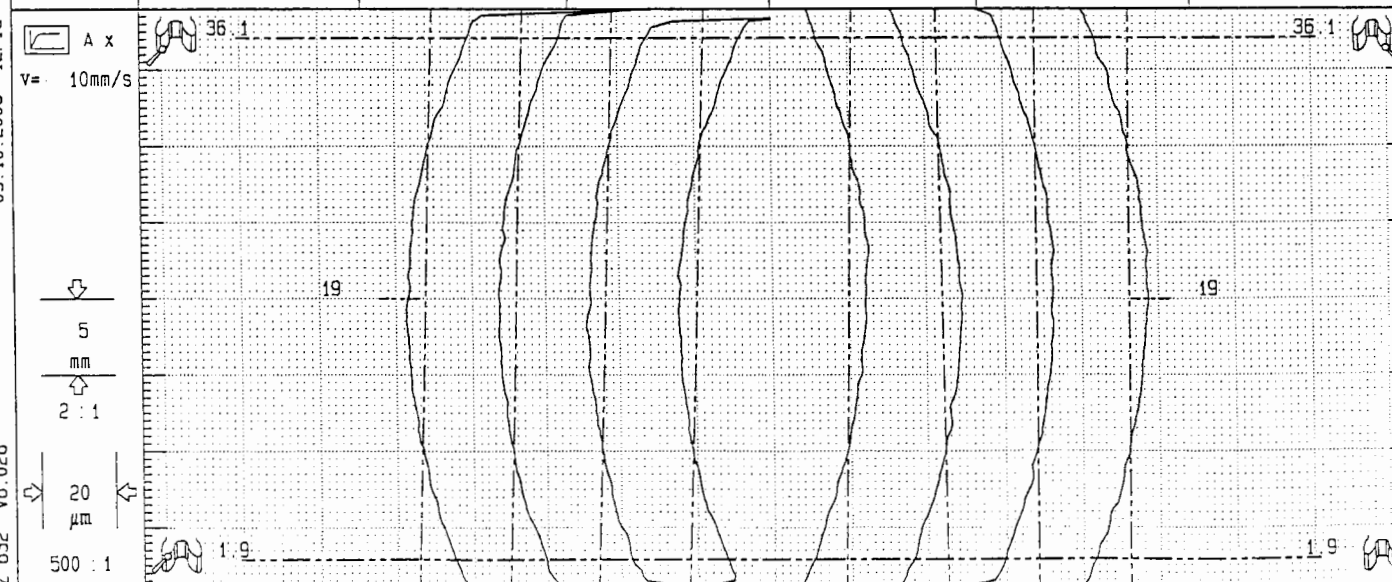
SPUR/HELICAL GEAR.



FS

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$\frac{1}{5}$	0/12	3.3	2	3.2	3.4	3.4	3.3	$F\alpha$	3.1	4.7	3.5	2.7	3	3.5	0/12
$\frac{1}{3}$	0/10	2.2	2	1.9	2.1	2	2.7	$f_{H\alpha}$	2.6	2.6	1.9	2.4	2	2.4	0/10
	+/-7	2	2	1.8	2.0	2.1	2.1	$f_{H\alpha}$	-0.6	-3.2	-2.3	-1.1	3	-1.8	+/-7
	-/-	2						$f_{H\alpha M}$						-1.8	-/-
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09.10.2003 12:18

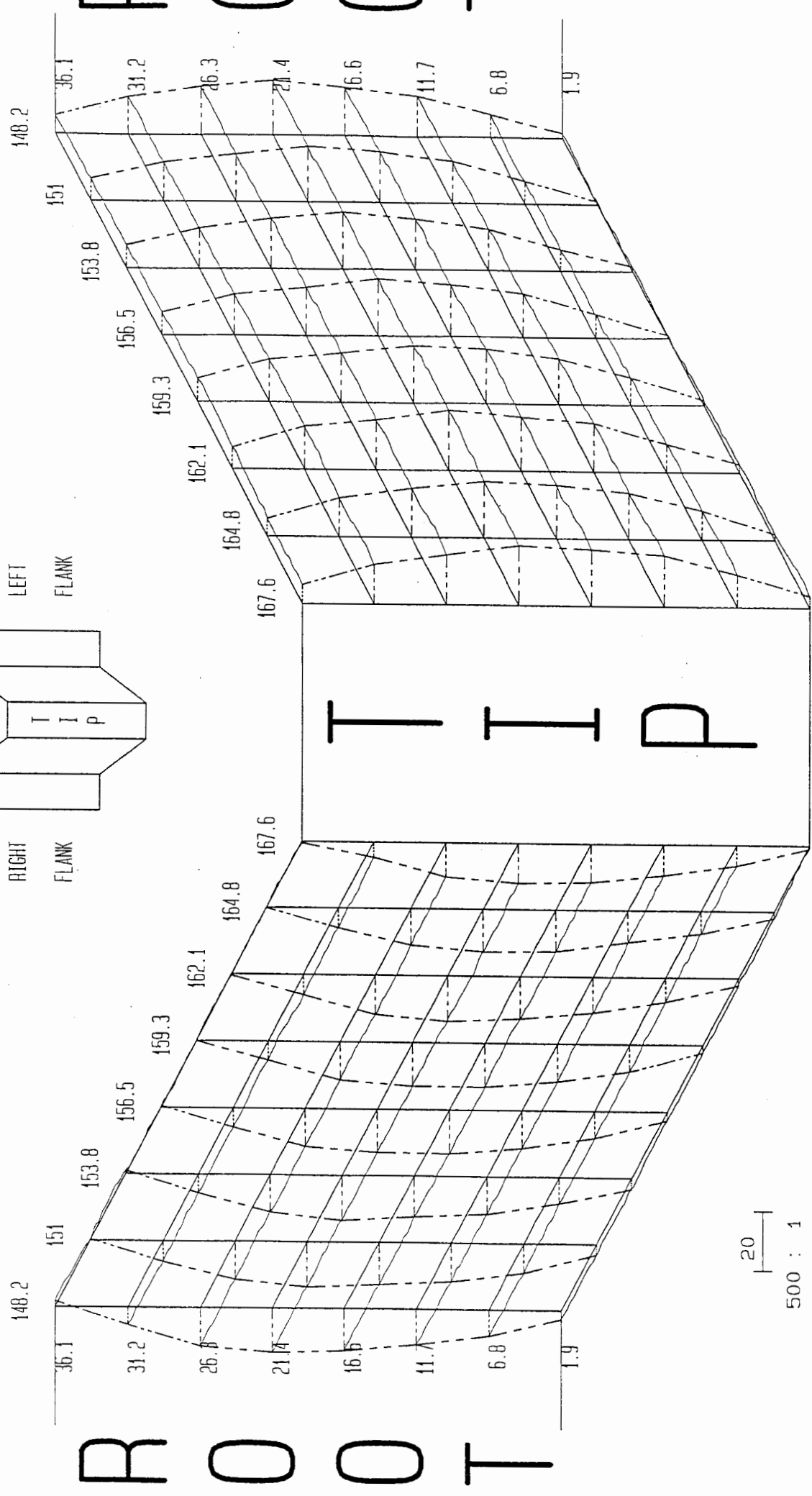


EMZ 632 V6.028

$\Sigma Q$	(...)	$\bar{x}$	Q	16	11	6	1	1	6	11	16	Q	$\bar{x}$	(...)	
$\frac{1}{5}$	0/8	16.6	8	16.6	16.8	16.7	16.4	$F\beta$	14.8	15.3	13.6	14.3	8	14.5	0/8
$\frac{1}{9}$	0/6	14.6	9	14.5	14.8	14.2	14.8	$f_{H\beta}$	14.2	14.4	13.6	14	9	14.1	0/6
	+/-6.5	-4.3	5	-4.0	-4.1	-4.5	-4.5	$f_{H\beta}$	-2.5	1.8	-1	-6	2	-3	+/-6.5
	-/-	-4.3						$f_{H\beta M}$						-3	-/-
	-/-	.5						$f_{\sigma\beta}$						4.3	-/-

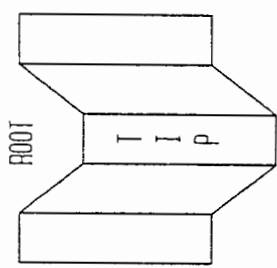
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FLANK

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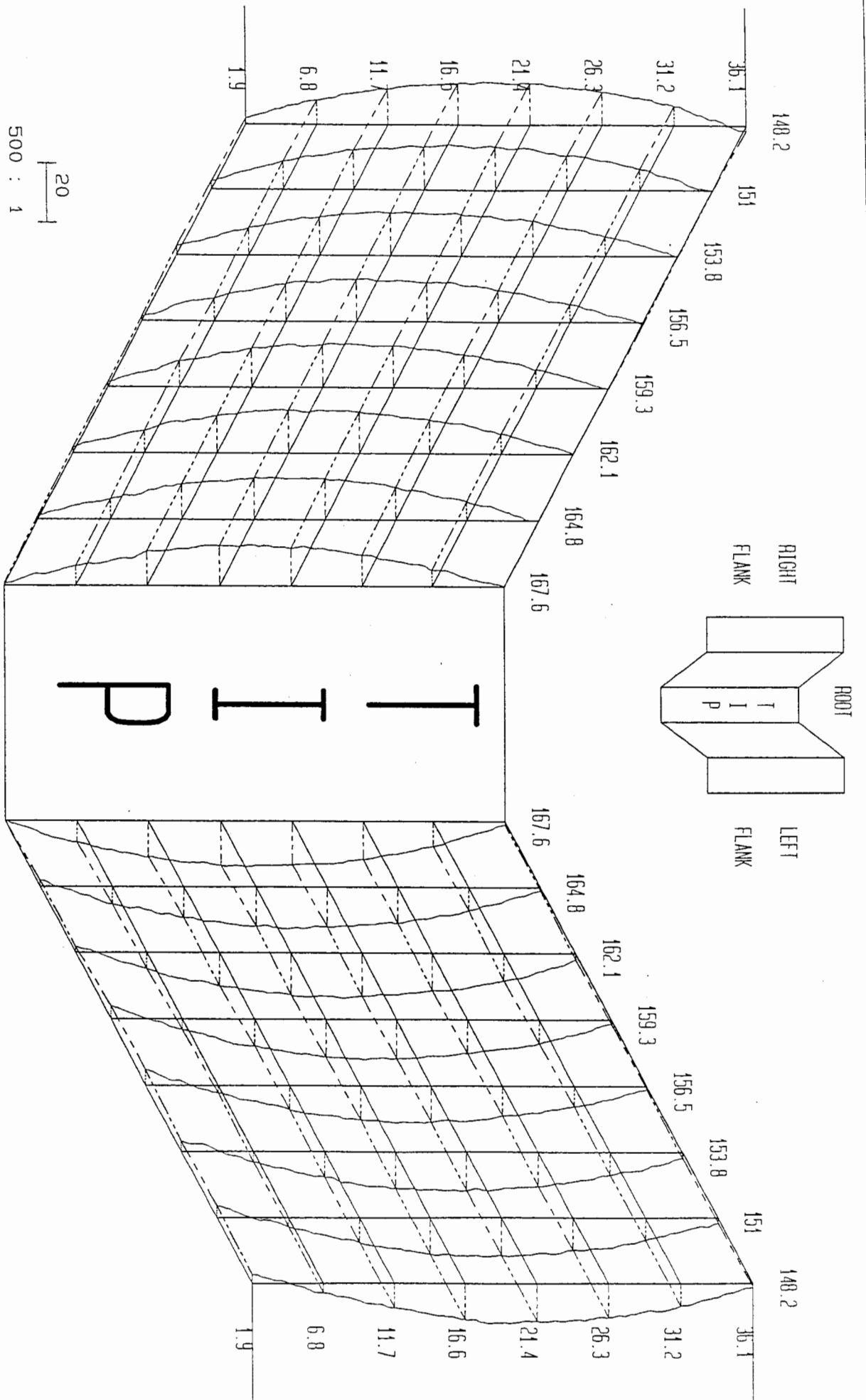
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KlingeInberg  
Soehne GmbH

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R O O T



PART NUMBER: MEGA LEFT MID/ N3 INSPECTOR: FS DATE: 09.10.2003 TIME: 12:36

KlängeInberg  
Soehne GmbH

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DIN 3961/62 / (mm)   
 SPUR/HELICAL GEAR   
 S.J.W   
 10.10.2003 17:16   
 EMZ 632 V6 028   
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UNIVERSITY OF NEWCASTLE

PITCH

MEGA RIGHT MID/./.

SERIAL NO 1



REMARKS NO 4

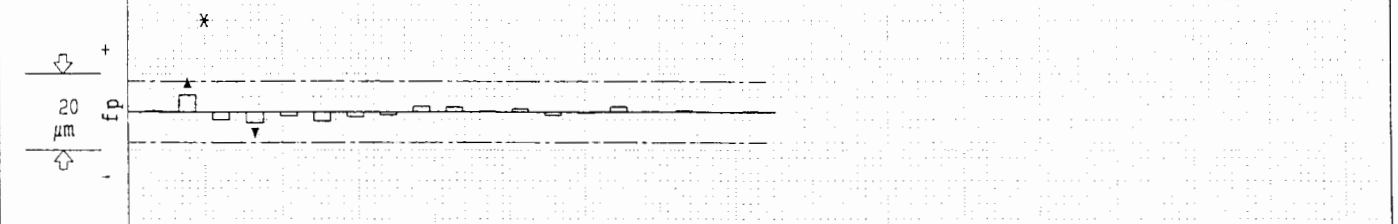
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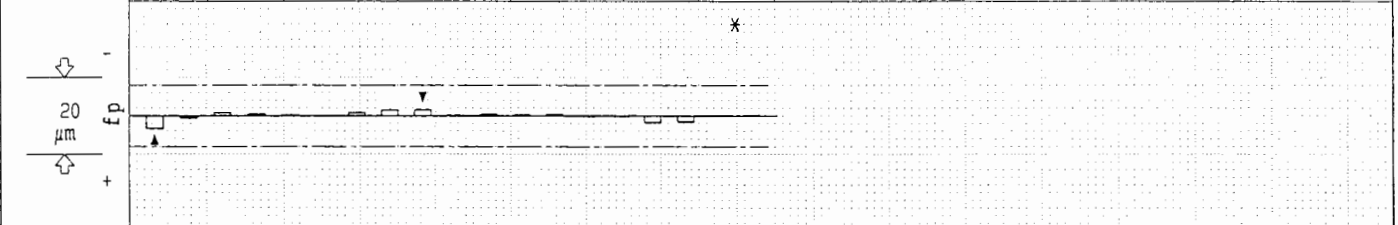
$m_n$  6.35 mm  $\beta$  30° 0' 0" / 30° 0' 0" b 38 mm  $d_b$  122.663/122.663 mm \*  $\frac{\Delta}{\Delta}$

NDP 4/1inch  $\beta_b$  26° 56' 46" / 26° 56' 46" x 2.008  $L\beta$  90->90/90->90 %  $\frac{\Delta}{\Delta}$

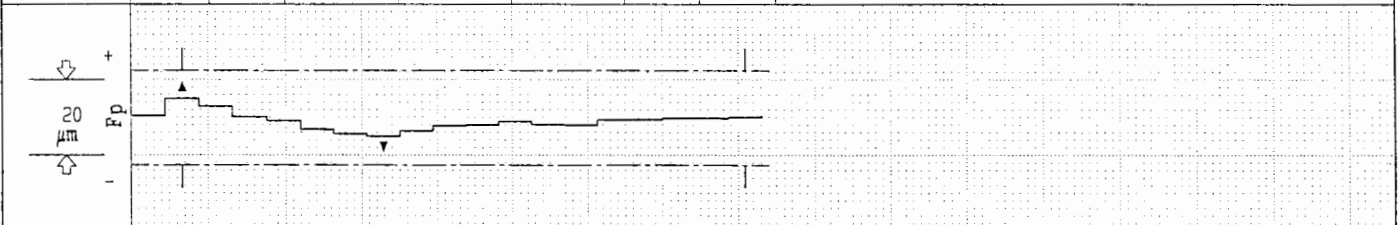
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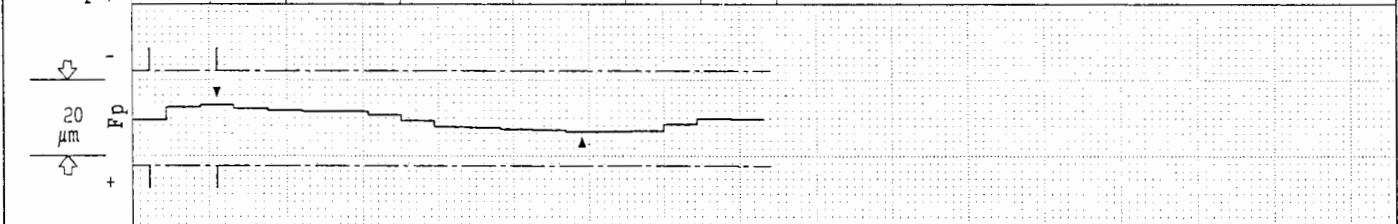
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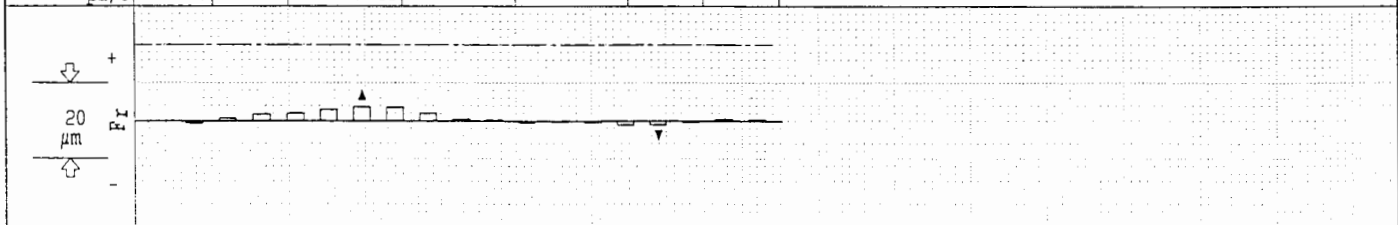
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$F_{pz/8}$	5	2	0 / 16	4.9	



$F_p$	5	1	0 / 25	7	▼ #3 ▲ #14
$F_{pz/8}$	5	1	0 / 16	3.9	



$F_r$	5	1	0 / 20	4.7	▼ #16 ▲ #7
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	20.634 <= 20.634 <= 20.634		95.754 <= 95.754 <= 95.754		190.915 <= 190.915 <= 190.915
	<= 21.443 <=		<= 96.334 <=		<= 192.07 <=

	132.049 <= 132.049 <= 132.049				<= 560.392 <=
	<= 132.782 <=				

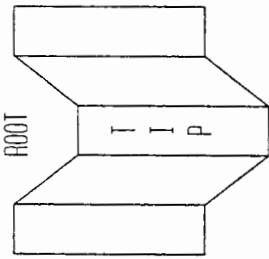
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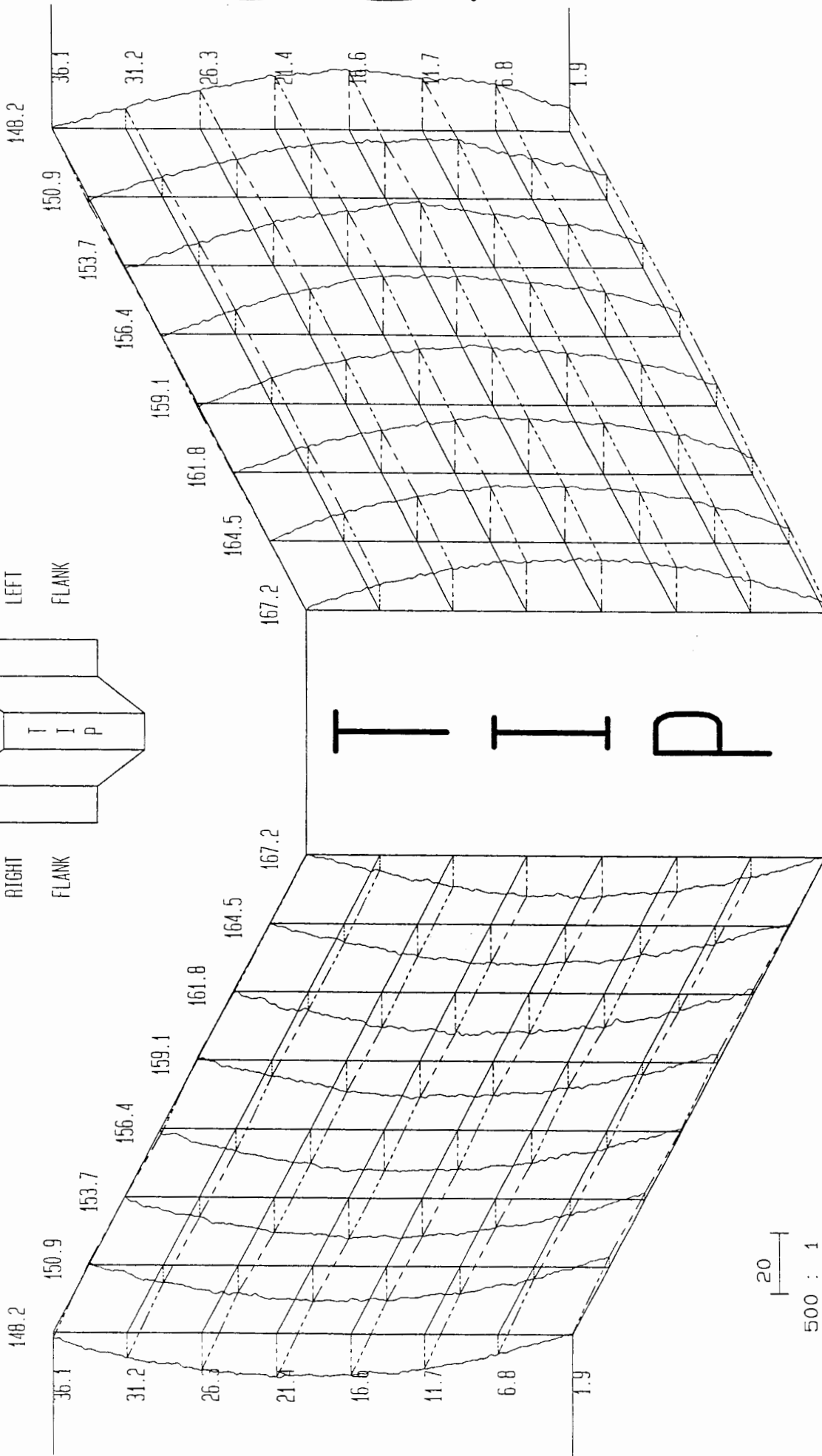
R O O T

R O O T



LEFT  
FLANK

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FLANK



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PART NUMBER: MEGA RIGHT MID/M<sup>2</sup>4 INSPECTOR: SJW DATE: 13.10.2003 TIME: 11:55

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Soehne GmbH

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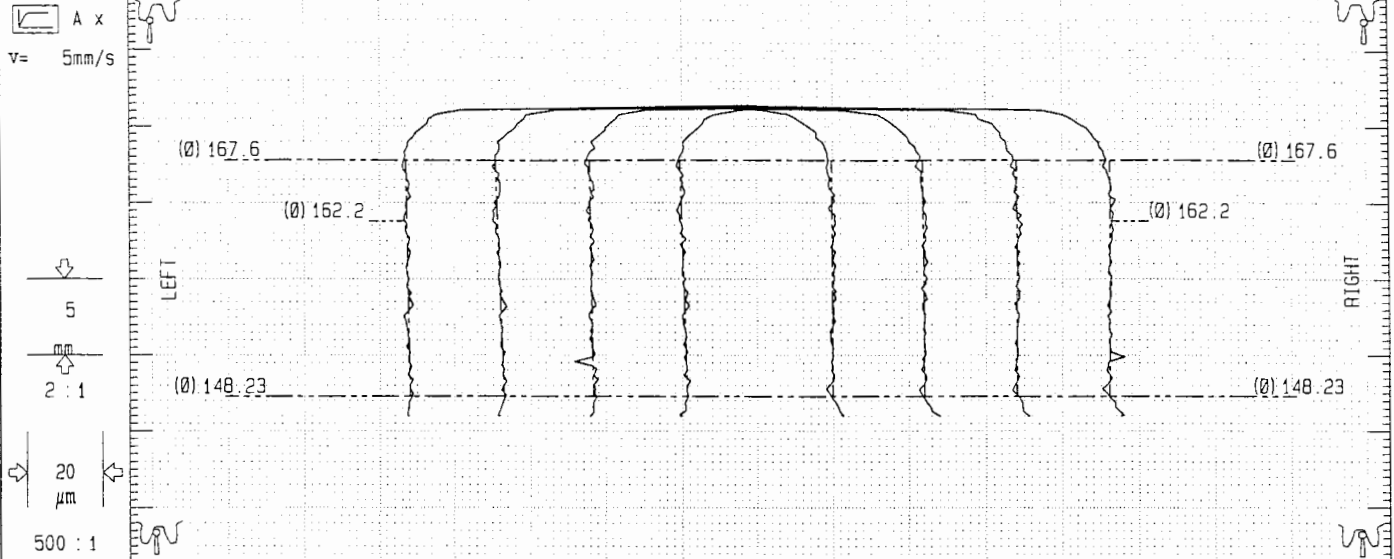
REMARKS NO4

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DIN 3961/62 / (mm)

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m <sub>n</sub>	6.35 mm	B	30° 0' 0" / 30° 0' 0"		b	38 mm	d <sub>b</sub>	122.663/122.663 mm		*		
NDP	4/inch	B <sub>b</sub>	26° 56' 46" / 26° 56' 46"		x	2.008	L <sub>g</sub>	90->90/90->90 %		$\frac{x}{\Delta}$	$\frac{L_g}{D_0}$	

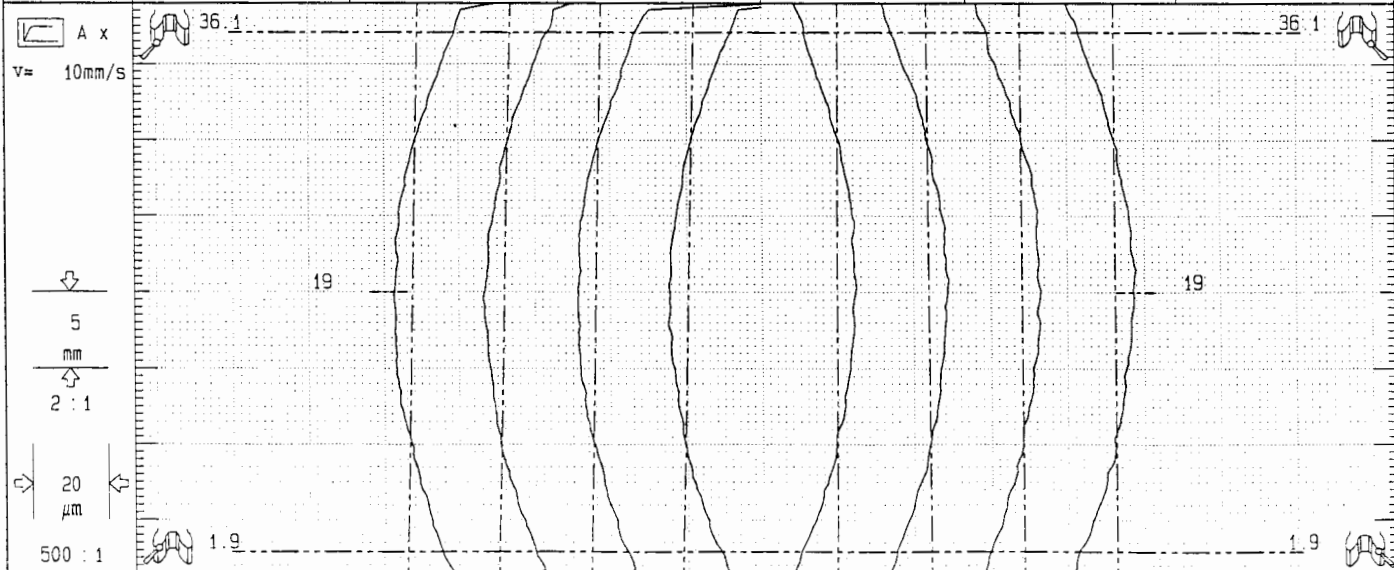
SPUR/HELICAL GEAR:



EQ	[...]	$\bar{x}$	Q	16	11	6	1		1	6	11	16	Q	$\bar{x}$	[...]
	0/12	4.1	4	2.8	3.7	6.4	3.6	$f_{H\alpha}$	2.8	3.3	3.1	5.9	3	3.8	0/12
	0/10	3.6	4	2.6	2.9	6.3	2.5	$f_{f\alpha}$	2.9	3.1	3.1	5.9	4	3.8	0/10
	+7	1.4	2	1.0	2.2	.7	1.8	$f_{H\alpha}$	-2	-4	.1	.3	1	0	+7
	-/-	1.4						$f_{H\alpha M}$						0	-/-
	-/-	1.5						$f_{\sigma\alpha}$						.7	-/-

SJM

13.10.2003 11:25



EQ	[...]	$\bar{x}$	Q	16	11	6	1		1	6	11	16	Q	$\bar{x}$	[...]
	0/8	16.3	8	16.3	17	15.2	16.6	$f_{H\beta}$	14.9	14.8	14	15.3	8	14.8	0/8
	0/6	15	9	14.8	15.3	14.5	15.2	$f_{f\beta}$	14.6	14.5	14	15.5	9	14.7	0/6
	+6.5	-3.1	3	-2.9	-3.4	-2.9	-3.2	$f_{H\beta}$	-6	.8	.7	.4	1	.3	+6.5
	-/-	-3.1						$f_{H\beta M}$						3	-/-
	-/-	.5						$f_{\sigma\beta}$						1.4	-/-

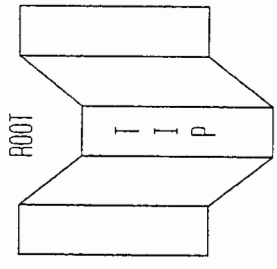
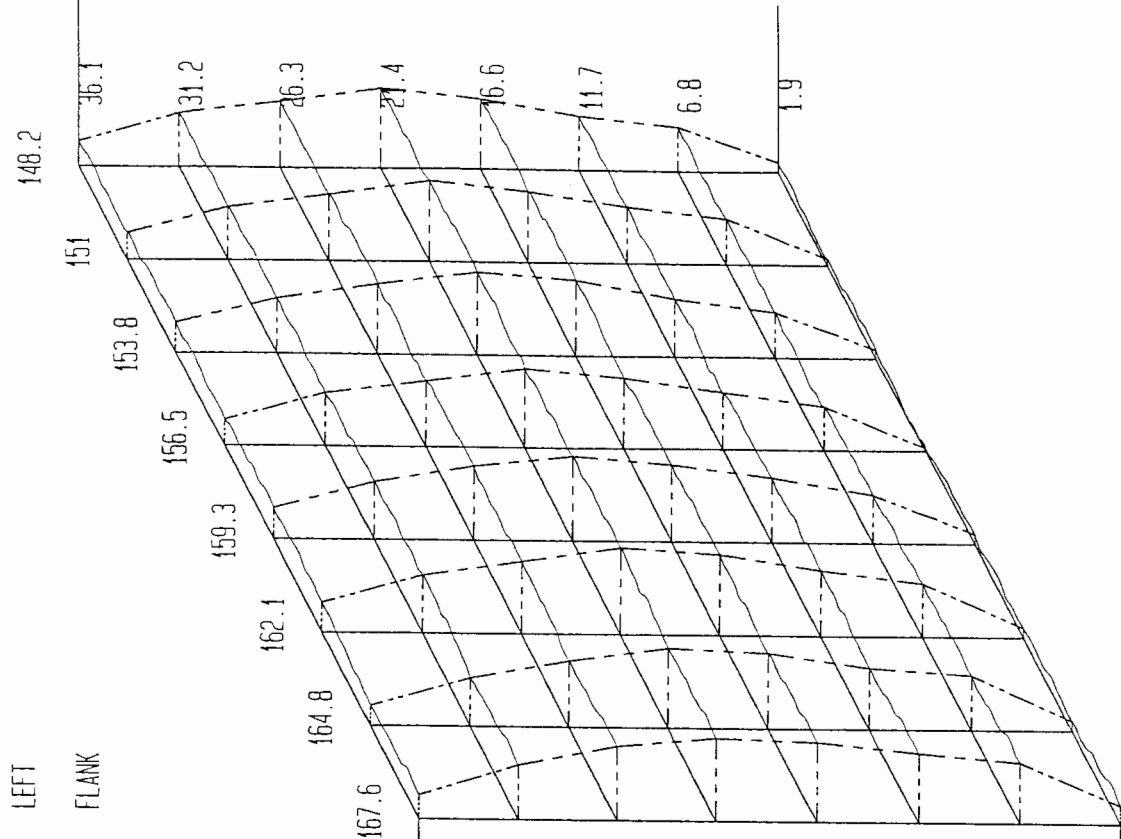
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DIN 3961/62 / (mm)   
 SPUR/HELICAL GEAR   
 S.J.H   
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<b>UNIVERSITY OF NEWCASTLE</b>				<b>PITCH</b>				SERIAL NO 1						
MEGA LEFT MID././.														
REMARKS NO4														
NGML														
z	19	L/L	$\alpha_n$	25°0'0"		$\emptyset$ 2mm					D <sub>0</sub> 139.315/139.315 mm			
m <sub>n</sub>	6.35 mm	$\beta$	30°0'0"/30°0'0"		b	38 mm	d <sub>b</sub>	122.663/122.663 mm		$\frac{x}{\Delta}$				
NDP	4/inch	$\beta_b$	26°56'46"/26°56'46"		x	2.008	L <sub>g</sub>	90->90/90->90 %		$\frac{\Delta}{\Delta}$				
v <sub>m</sub> =	10mm/s	$\perp Q$	=Q	[...]										
v <sub>p</sub> =	15mm/s													
*														
↓ +														
20 μm														
↑ -														
f <sub>p</sub>	5	1	0/ 8	1.9			▼ #6	▲ #2						
f <sub>u</sub>	5	3	0/ 10	3.3					#3					
*														
↓ -														
20 μm														
↑ +														
f <sub>p</sub>	5	1	0/ 8	1.7			▼ #7	▲ #2						
f <sub>u</sub>	5	1	0/ 10	2.2					#8					
↓ +														
20 μm														
↑ -														
F <sub>p</sub>	5	1	0/ 25	5			▼ #10	▲ #2						
F <sub>pz/8</sub>	5	1	0/ 16	2.8										
↓ -														
20 μm														
↑ +														
F <sub>p</sub>	5	1	0/ 25	3.2			▼ #9	▲ #15						
F <sub>pz/8</sub>	5	1	0/ 16	2.2										
↓ +														
20 μm														
↑ -														
F <sub>r</sub>	5	1	0/ 20	3.3			▼ #2	▲ #10						
=														
20.634<=20.634<=20.634														
=														
<=20.967<=														
=														
95.754<=95.754<=95.754														
=														
<=95.993<=														
=														
190.915<=190.915<=190.915														
=														
<=191.392<=														
=														
18														
=														
18														
=														
132.049<=132.049<=132.049														
=														
<=132.351<=														
=														
<=559.884<=														
=														
180														

R O O T



LEFT FLANK

RIGHT FLANK

R O O T

20  
500 : 1

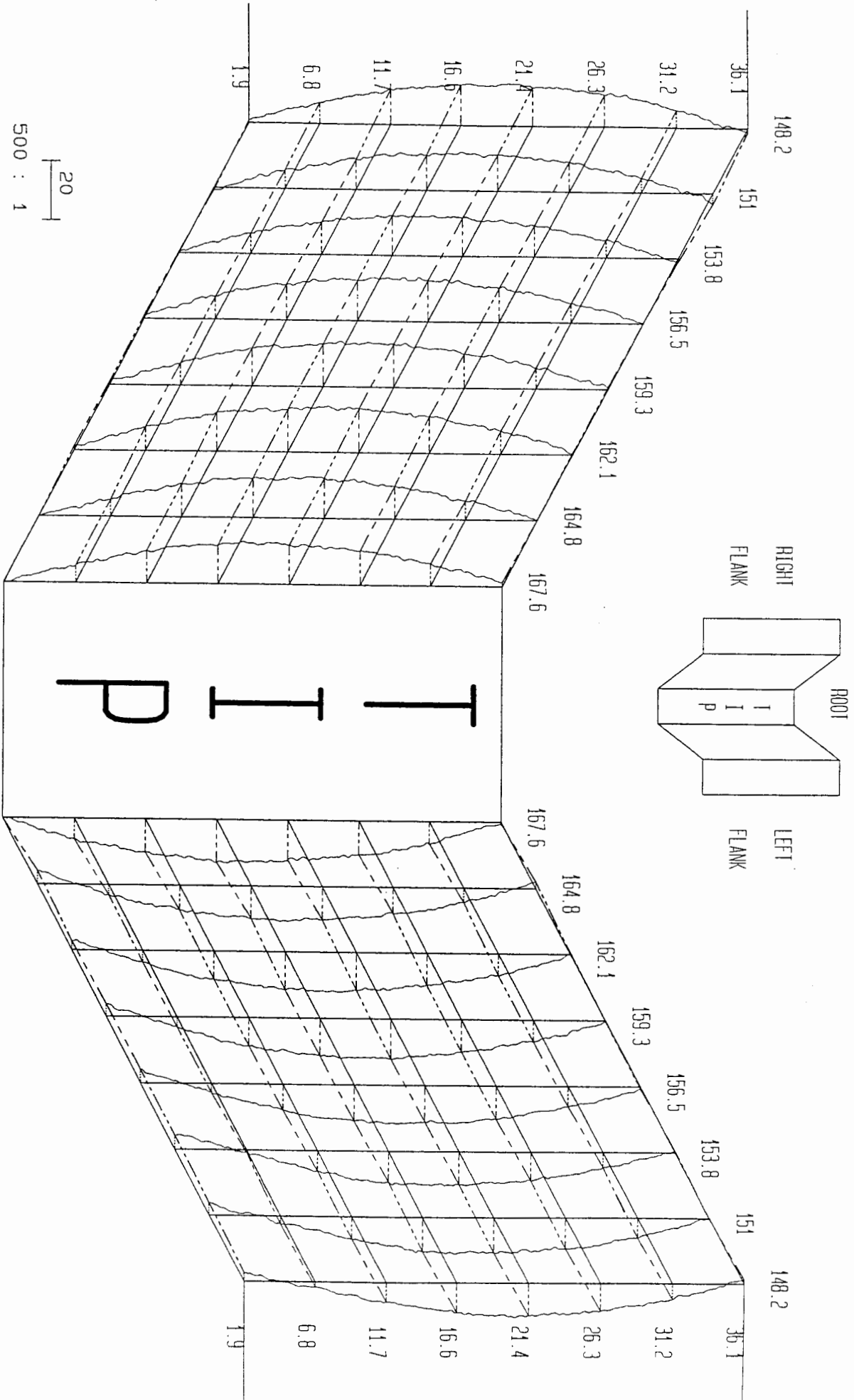
PART NUMBER: MEGA LEFT MID/./. INSPECTOR: SJW DATE: 13.10.2003 TIME: 11:34

KlingeInberg  
Soehne GmbH

TOPOGRAPHY

UNIVERSITY OF .

R O O T



PART NUMBER: MEGA LEFT MID/./. INSPECTOR: SJW DATE: 13.10.2003 TIME: 11:38

Klingelberg  
Soehne GmbH

# TOPOGRAPHY

UNIVERSITY OF .

R O O T

# RANK TAYLOR HOBSON

Form Talysurf Series

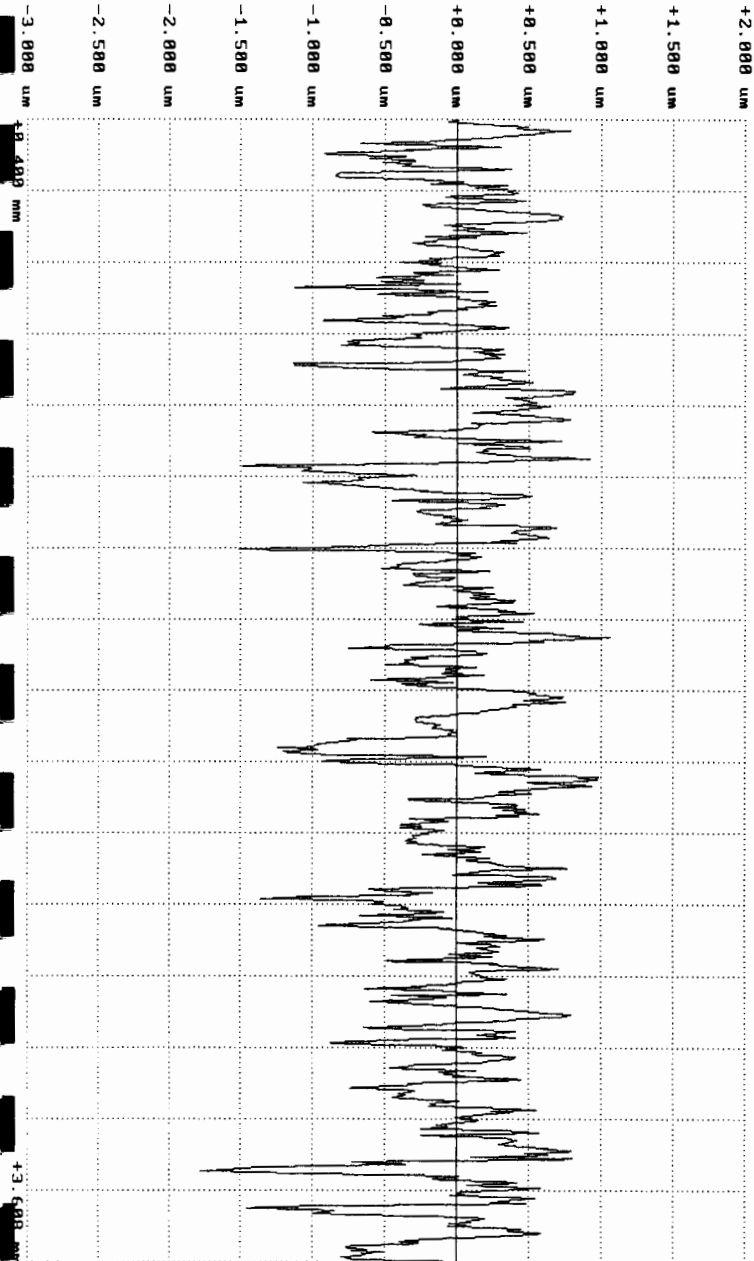
NEWCASTLE UNIVERSITY DESIGN UNIT

15/10/03 14:03:29  
Measurement Filename : RH3\_02  
Rough/Gauss/4\*0.8mm, 100:1/Convex

### COMPLETE MODIFIED PROFILE

Horizontal Scale : 200.000 um per division  
Horizontal Magnification : x 47.4  
Vertical Scale : 0.500 um per division  
Vertical Magnification : x 18960.0

WARNING : ALL PROFILE POINTS NOT PRINTED



S Rad 56.3109mm

Ra	0.3601 um	Rq	0.4584 um	Rp	1.0757 um
Rv	1.7733 um	Rt	2.8491 um	Delq	4.1855 deg
RzISO	1.7707 um	RzDIN	2.4522 um		

# RANK TAYLOR HOBSON

Form Talysurf Series

NEWCASTLE UNIVERSITY DESIGN UNIT

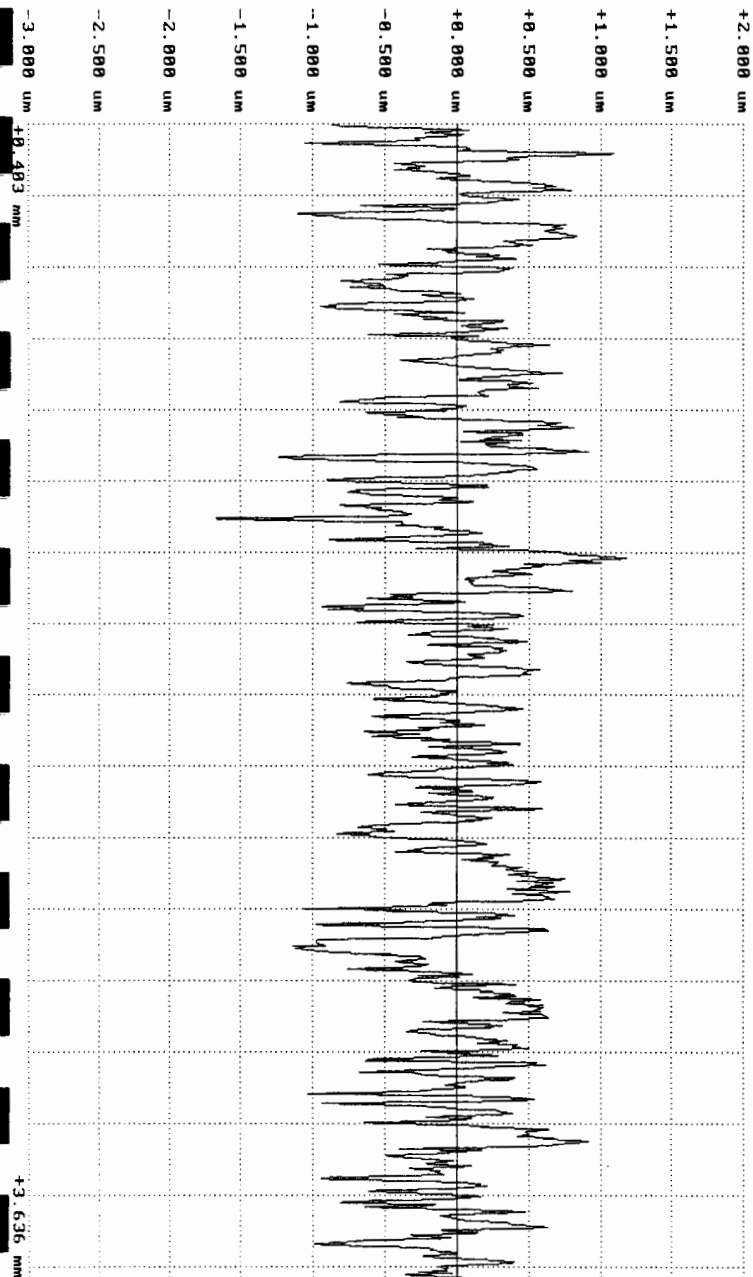
15/10/03 09:50:19  
Measurement Filename : LH3\_02  
Rough/Gauss/4\*0.8mm, 100:1/Convex

MEGA

### COMPLETE MODIFIED PROFILE

Horizontal Scale : 200.000 um per division  
Horizontal Magnification : x 47.4  
Vertical Scale : 0.500 um per division  
Vertical Magnification : x 18960.0

WARNING : ALL PROFILE POINTS NOT PRINTED



LS Rad 58.0195mm

Ra	0.3558 um	Rq	0.4446 um	Rp	1.1861 um
Rv	1.8963 um	Rt	3.0024 um	Delq	4.2383 deg
RzISO	1.7698 um	RzDIN	2.3285 um		



# RANK TAYLOR HOBSON

Form Talysurf Series

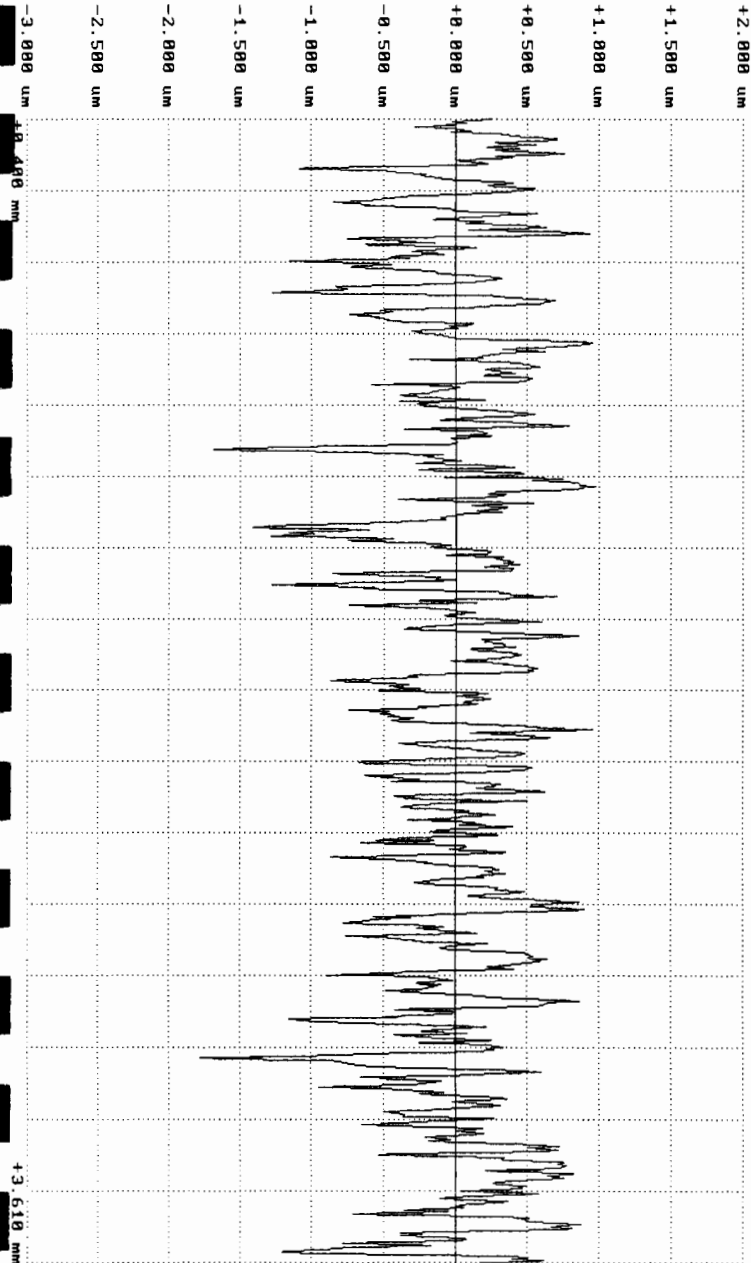
## NEWCASTLE UNIVERSITY DESIGN UNIT

15/10/83 10:16:23  
Measurement Filename : LH4\_02  
Trough/Gauss/4\*0.8mm, 100:1/Convex

### COMPLETE MODIFIED PROFILE

Horizontal Scale : 200.000 um per division  
Horizontal Magnification : x 47.4  
Vertical Scale : 0.500 um per division  
Vertical Magnification : x 18960.0

WARNING : ALL PROFILE POINTS NOT PRINTED



LS Rad 54.5410mm

Ra	0.3656 um	Rq	0.4578 um	Rp	0.9795 um
Rv	1.8568 um	Rt	2.8355 um	Delq	4.1661 deg
RzISO	1.8365 um	RzDIN	2.3696 um		