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(A)

# SQUARENESS ERROR MAPPING OF A COORDINATE MEASURING MACHINE USING A 2-DIMENSIONAL REFERENCE OBJECT.\*

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(Submitted for Publication)

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## 1. ABSTRACT

This publication describes and documents the calibration procedure to improve the accuracy (as specified by the manufacturer) of a MITUTOYO C806-10 CMM (Coordinate Measuring Machine) by 50 %. This goal was achieved with the assistance of the PTB (Physikalische Technische Bundesanstalt) in Braunschweig, Germany. The PTB is the equivalent of the NIST in Washington DC.

## 2. INTRODUCTION

Smaller and therefore cheaper CMMs (Coordinate Measuring Machines) are becoming quite popular. Considering that it has been only a few years since the so-called bench top CMMs first appeared, the number of such units now in the market is quite surprising. For the fiducialization effort of the Final Focus Test Beam (FFTB) electro magnets a CMM was required which could be operated next to the fully powered magnets. A bench top CMM was essential and a MITUTOYO C806-10 was selected.

Although these bench top CMMs provide fairly good measurement results, they are less accurate and less accurately assembled than a first order CMM. A method is suggested by Dr. Trapet<sup>1</sup> to improve the accuracy of CMMs. The PTB developed a software package to determine 22 error parameters of a CMM. These 22 parameters define a column type CMM completely. Unfortunately this software package is still unavailable but an agreement was reached that the PTB will assist us to determine a subset of error parameters. The squareness errors of a CMM usually account for 80% of the error budget. Therefore we decided that six parameters ( three squareness and three non-linearity parameters) will be a sufficient number of parameters to be determined for our MITUTOYO C806-10 CMM.

## 3. CONCEPT OF METHOD

Trapet's method is easy to use and only low priced equipment is needed. It achieves a satisfactory accuracy and facilitates traceability. A pre-calibrated, 2-dimensional object (bore plate) is measured in four defined positions in the working space. The software package derives subsequently from the plate measurements the final parametric errors of the CMM. It is well suited for calibration purposes.

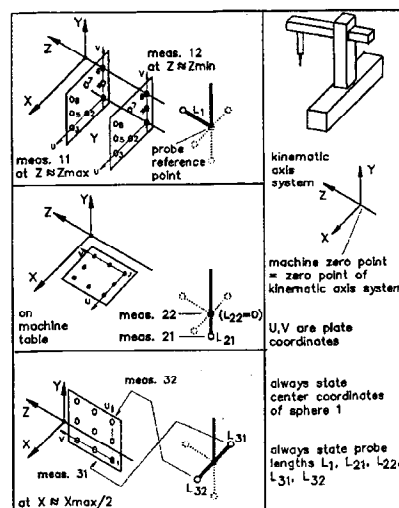


Fig. 1: The 6 plate measurements required for a full error analysis of a column type CMM<sup>2</sup>

Fig. 1 shows the four plate positions necessary for the reference object, using a bore plate (Fig. 2). With the five different probe styli in Fig. 1 and Fig.2 the measurements are carried out. By measuring with two central styli (L21 and L22) we have the same effect as measuring once in the lower and once an upper position (positions 21 and 22). In each of the two vertical positions 11 and 12, the plate is measured from one side with stylus L1. The center position between the three long horizontal styli (L1, L31, L32) coincides with the short central stylus L22. The short central stylus L22 represents the reference stylus for which the results (parametric errors) are to be calculated.

<sup>1</sup>Dr.- Ing. E. Trapet, Dr.-Ing. F. Wäldele; Determination of the parametric errors of Coordinate Measuring Machines and Machine Tools using reference objects. Appendix E.

<sup>2</sup> PTB drawing 5.32

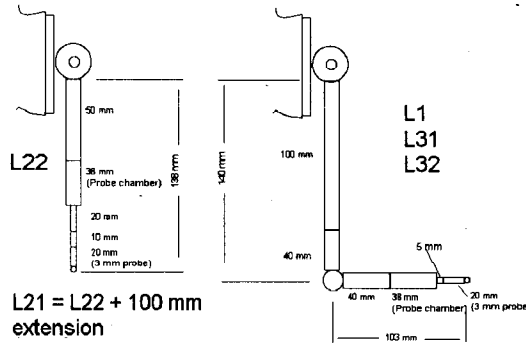


Fig. 2: Probe assemblies for Mitutoyo plate measurements

#### 4. BORE PLATE

The bore plate was designed and manufactured at SLAC (Fig. 3) according to design specifications from the PTB. The material was chosen to be series 6000 aluminum with a temperature expansion coefficient of  $23.6 \cdot 10^{-6}$  per  $1^{\circ}$  Celsius.

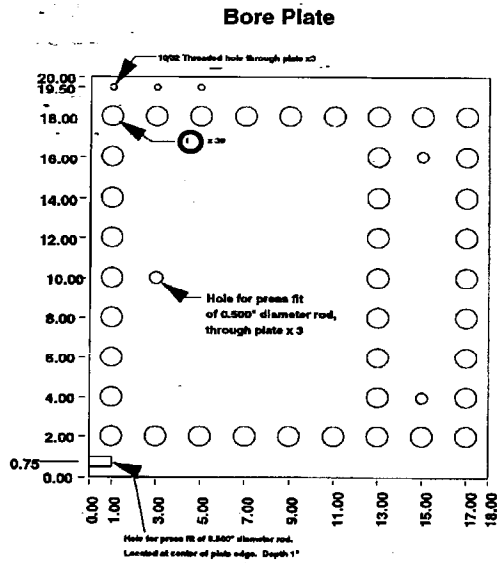


Fig. 3: Bore plate design (all dimensions in inches)

The plate was measured on the LEITZ PM 12106 CMM which is certified for a volumetric accuracy of  $0.8 \mu\text{m} + 2 \text{ppm}$ . The measurements were performed according to the swing round method (Appendix B), as recommended by the PTB. The plate was measured in all four positions. The temperature at the beginning and at the end of each position was recorded. The average of all four positions reduced to  $20^{\circ}$  Celsius represented the calibration values.

#### 5. MEASUREMENTS

We chose to evaluate error parameters for 2 areas of the Mitutoyo. The areas were labeled "upstream volume" and "downstream volume". For each position the holes 1 through 32 were measured in the middle of the plate as 2 circles with 4 probings each. The four probings were always in the direction of the coordinate axis. It was chosen to measure in the middle of the plate in order to minimize the effect of a possible bending of the plate. The circles were measured about 1mm vertically separated and all 8 measurements evaluated as cylinders. The cylinder axis was intersected with the plate's symmetry plane going through the center of the plate (top surface offset by half of the plate thickness). The temperature for each plate position was recorded.

#### 6. RESULTS

The plate measurements were evaluated by the PTB in Germany and resulted in following squareness errors in regard to the CMM coordinate system (Fig.4):

Upstream volume	Downstream volume
SQUARE_XY = -0.000057 [rad]	SQUARE_XY = -0.000087 [rad]
SQUARE_XZ = 0.000035 [rad]	SQUARE_XZ = 0.000049 [rad]
SQUARE_YZ = 0.000120 [rad]	SQUARE_YZ = 0.000121 [rad]

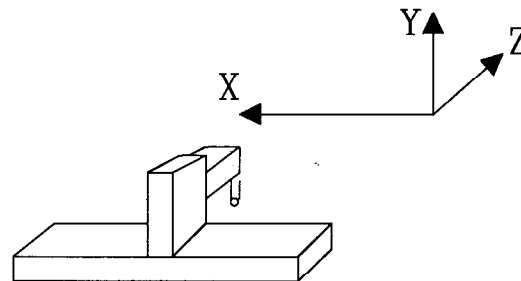


Fig.4: Mitutoyo calibration coordinate system

The temperature variations during our measurements didn't allow a reliable determination of the scale parameters.



The squareness parameters are applied to the coordinates as follows:

$$\begin{aligned} X_{\text{corrected}} &= X - Y * \text{SQUARE\_XY} - Z * \text{SQUARE\_XZ} \\ Y_{\text{corrected}} &= Y - Z * \text{SQUARE\_YZ} \\ Z_{\text{corrected}} &= Z \end{aligned}$$

To test our results the above squareness parameters were applied to 6 of the 12 plate measurements for both volumes. We compared the plate coordinates to the calibrated plate values from the LEITZ CMM before and after the corrections were applied (Appendix D). Uncorrected data show discrepancies to the plate calibrations of up to 47  $\mu\text{m}$ . If correction parameters of squareness are applied these discrepancies show as below 15  $\mu\text{m}$ . Additional temperature correction (expansion of scales and expansion of plate) results in values of less than 10  $\mu\text{m}$  by comparing a plate measurement on the MITUTOTO to the plate calibration coordinates (LEITZ CMM). It can be concluded that the application of the squareness

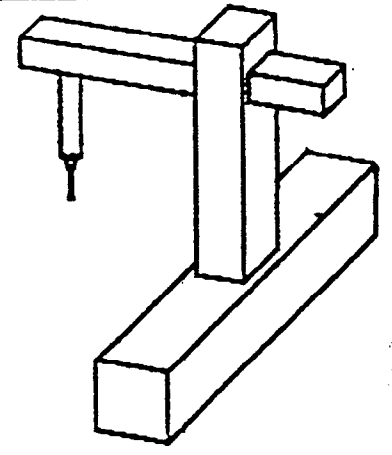
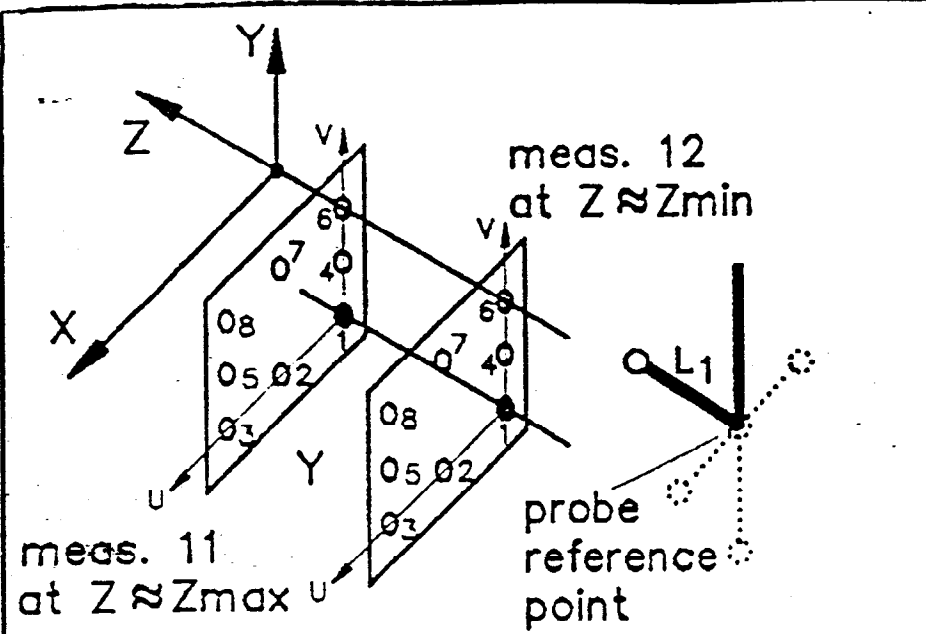
parameters can improve the accuracy of the CMM by at least 50 %. The temperature has to be kept constant at the temperature specified for the machine. A variation of 1°Celsius would result a) in expansion of the CMM scales which could introduce 5  $\mu\text{m}$  on a volume of 400 mm and b) expansion of the material e.g. aluminum 10  $\mu\text{m}$  on a volume of 400 mm. The Mitutoyo is certified by the manufacturer to have a volumetric accuracy of 30  $\mu\text{m}$  +35ppm. It can be safely stated that with this procedure we improved the accuracy of the CMM by 50%.

## 7. ACKNOWLEDGMENTS

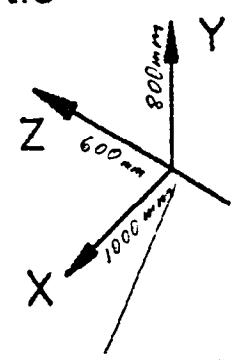
We would like to thank Dr. Trapet from the PTB in Germany for his assistance and help to make this calibration possible. We would also like to acknowledge hereby the contributions of many members of the SLAC staff, in particular B. Wagner who made all the necessary measurements.



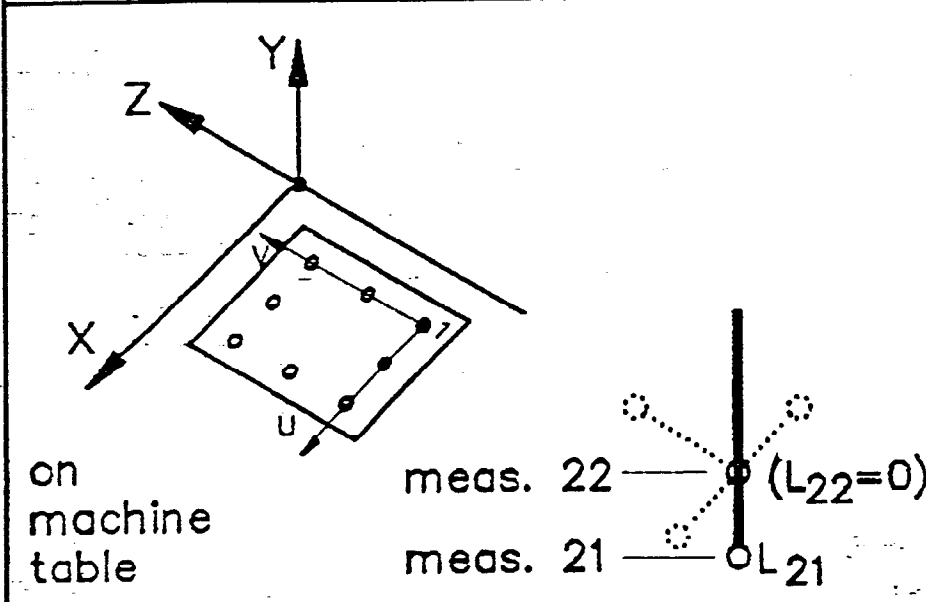
## APPENDIX A



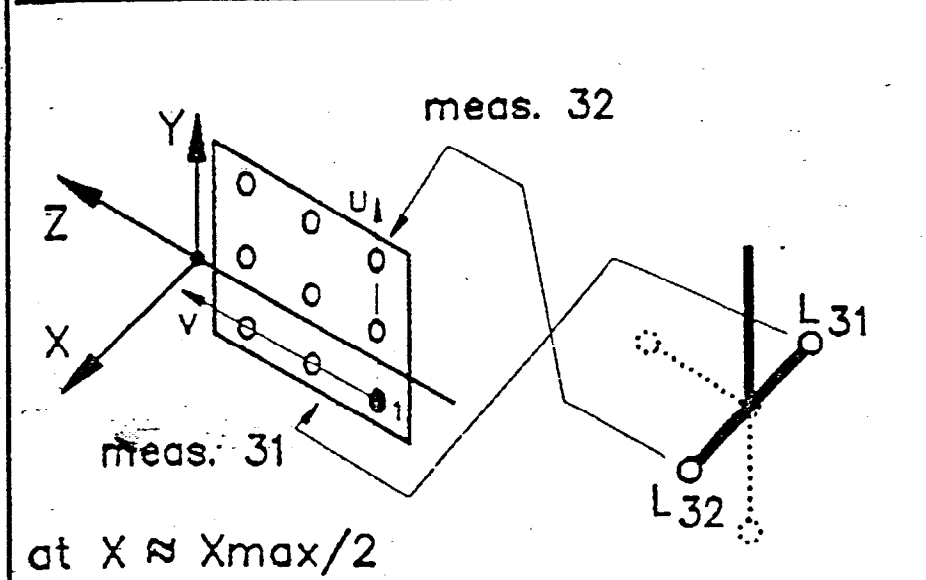
kinematic  
axis  
system



machine zero point  
= zero point of  
kinematic axis system



U, V are plate  
coordinates



always state  
center coordinates  
of sphere 1

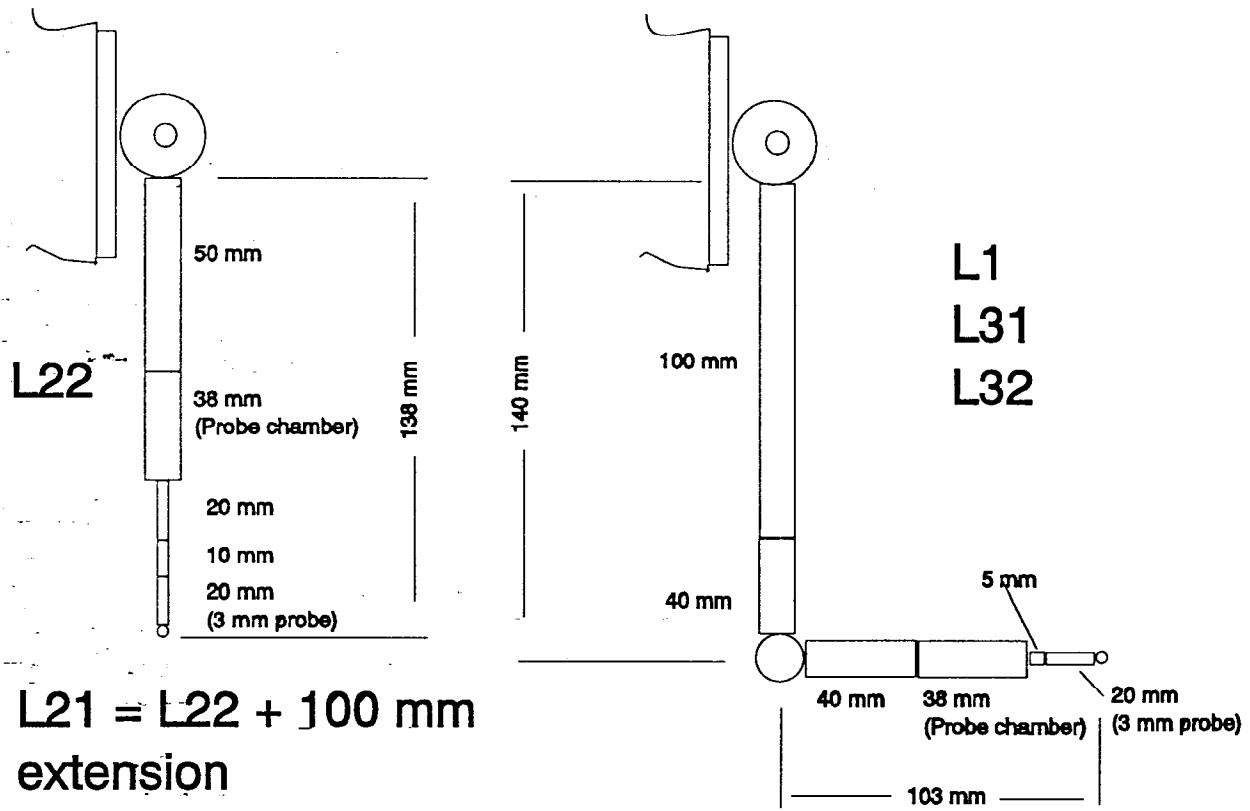
always state probe  
lengths  $L_1, L_{21}, L_{22},$   
 $L_{31}, L_{32}$

The 6 plate measurements  
required for a full error analysis  
of a column type CMM

**PTB**

5.32

# Probe setups for Mitutoyo plate measurements




# MEMORANDUM

SLAC SURVEY &  
ALIGNMENT GROUP

TELEPHONE (415) 926-2286  
BIN# 21



TO: PURCHASING  
CC: Robert Ruland  
FROM: Bernd Wand  
DATE: 1-13-92  
SUBJECT: Sole source justification for FFTB CMM calibration



The FFTB Coordinate Measurement Machine (CMM) from MITUTOYO doesn't meet the accuracy requirements which are required of FFTB magnet fiducilization application. A procedure developed by the PTB, the German equivalent of our NIST, would allow us to map the error parameters of the CMM like squareness, straightness and linearity of the 3 axis. With those errors mapped it can be expected that we have compensated for ~ 80% of the total error budget. PTB is willing to assist us with this error mapping of the CMM for ~ 6000 DM ( ~ \$4000). The PTB is the only facility in the world which is capable of rendering this assistance.

Dr. Trapet  
Physikalisch Technische Bundesanstalt, Labor 5.32  
Bundesallee 100, Postfach 3345  
D - 3300 Braunschweig  
FAX 011-49-531-592-4006  
Phone: 011-49-531-592-5320

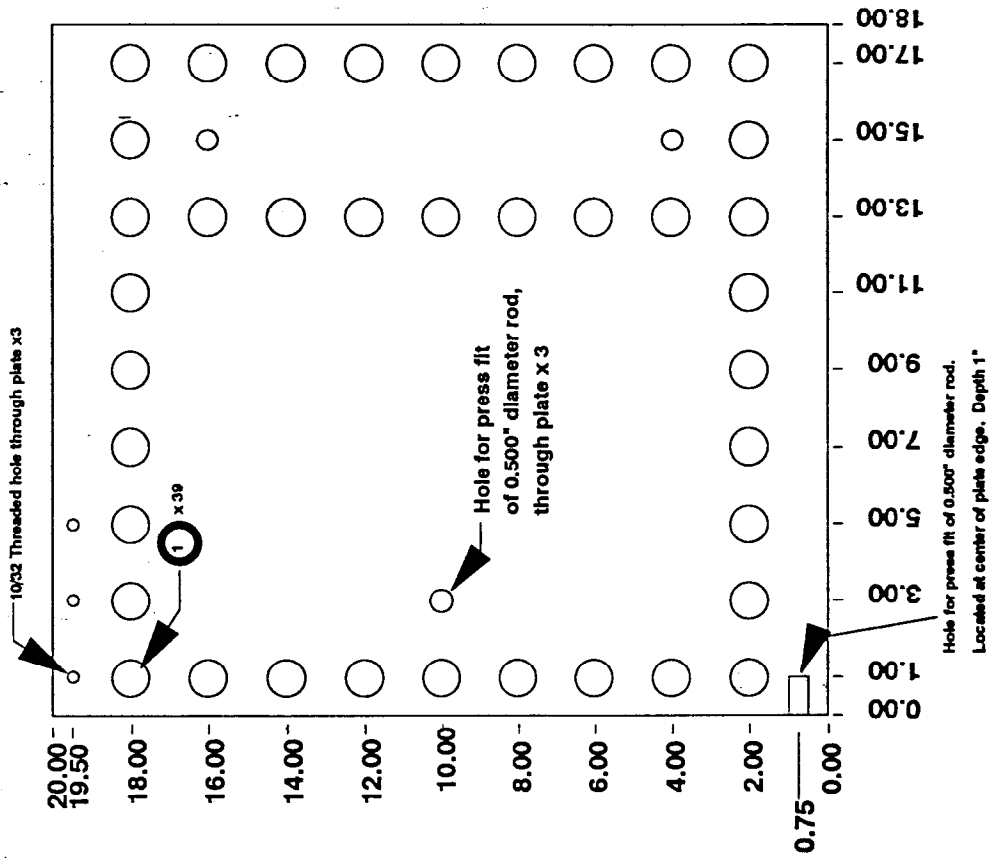




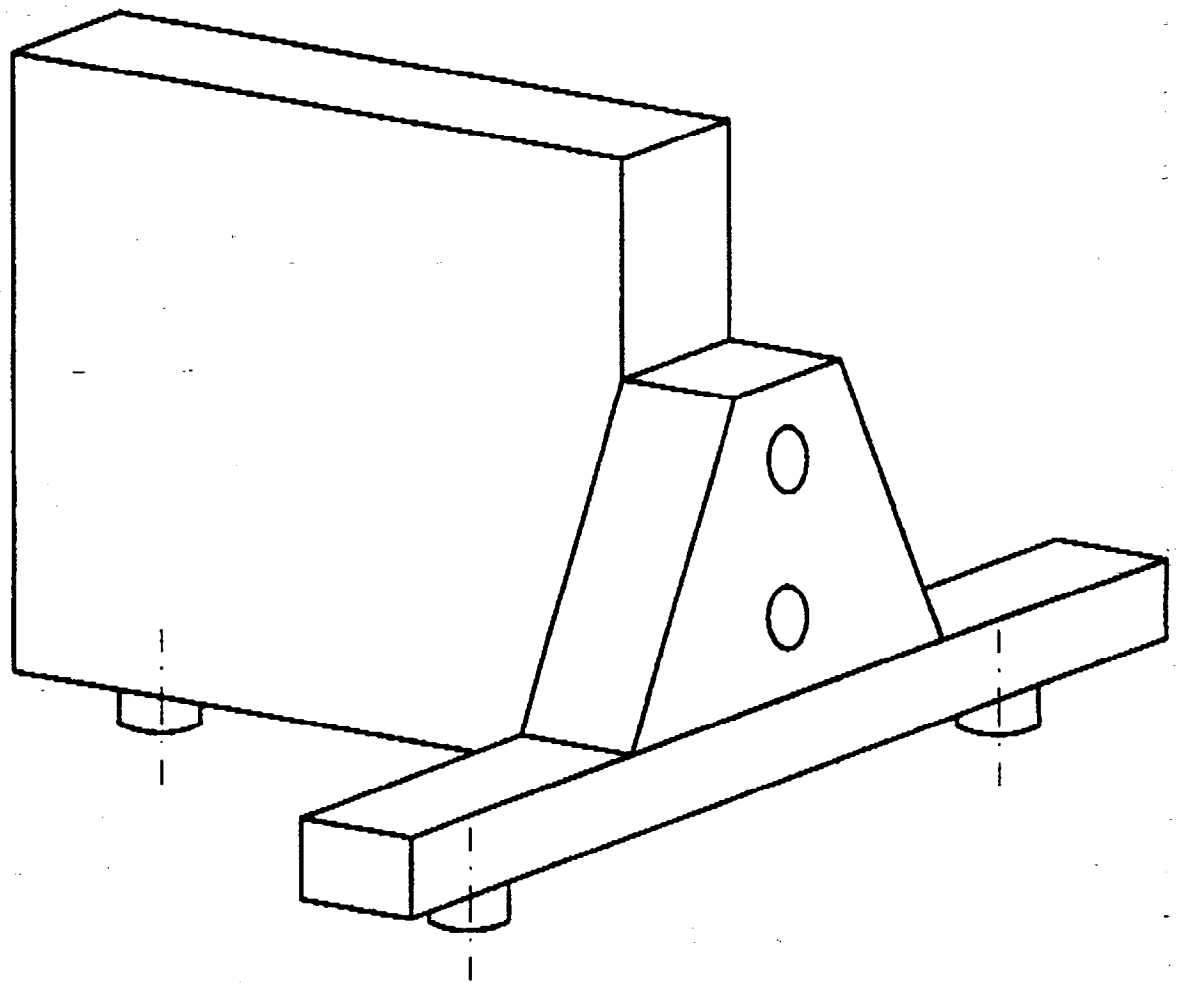
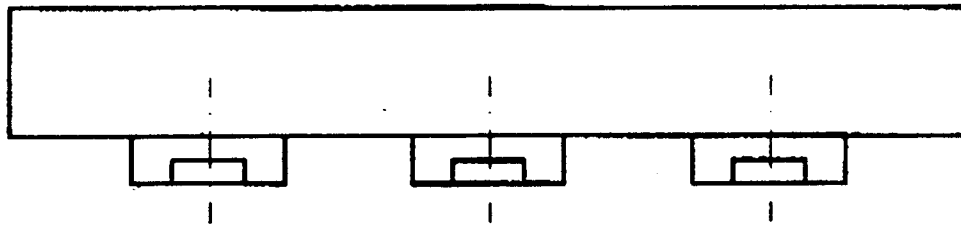
## APPENDIX B

WO# 06-0169-2

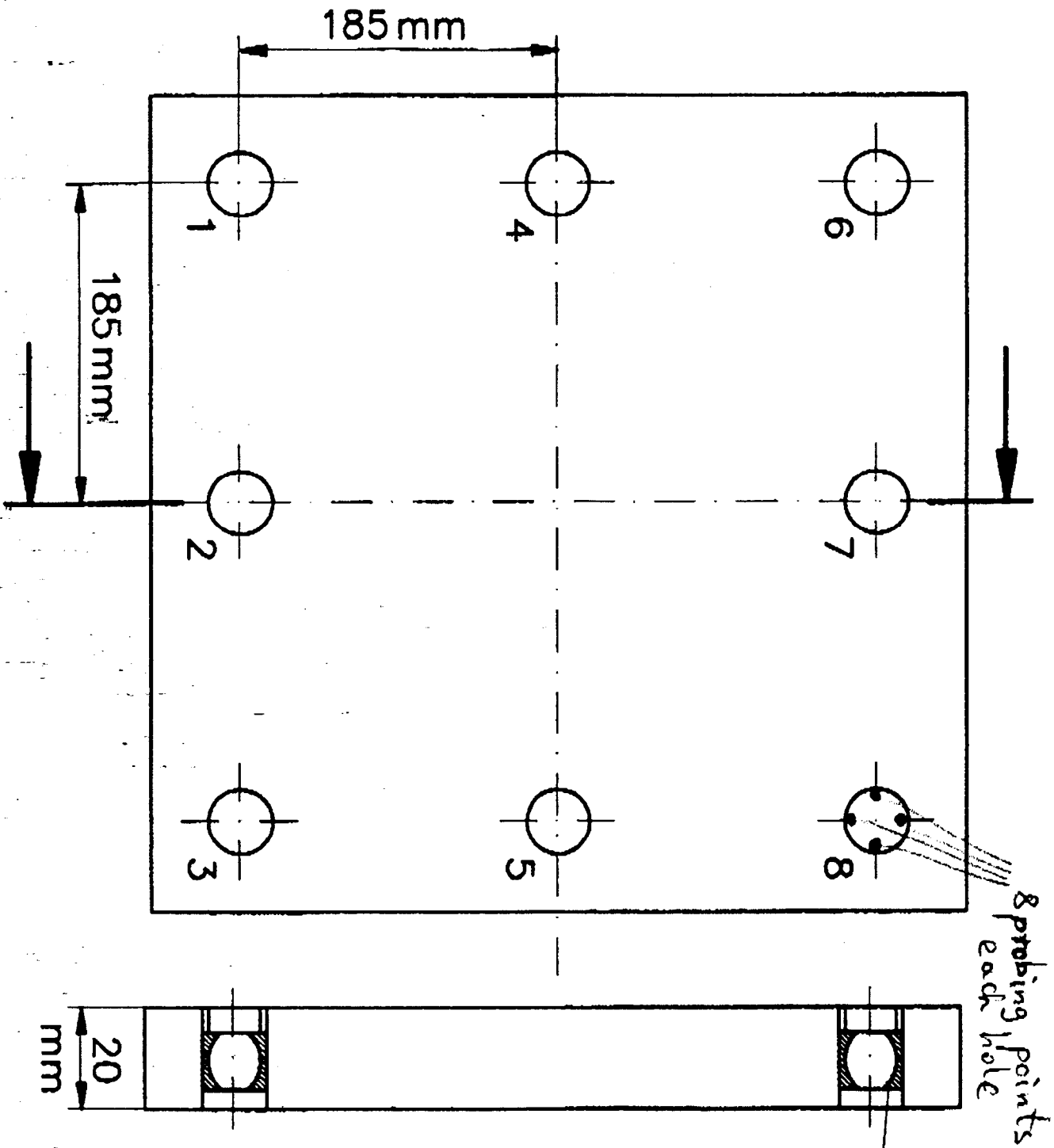
# Bore Plate



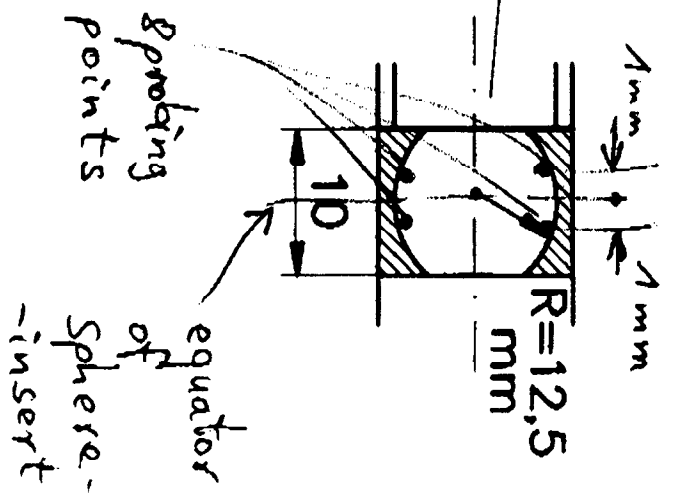
All dimensions are inches.



Fixturings for the test plate



Test plate from steel or aluminium





## Calibration plate for MITUTOYO CMM as measured on the LEITZ CMM (4-17-92)

Plate material: Series 6000 Aluminum

Temperature expansion coefficient:  $23.6 * 10^{-6} / ^{\circ}\text{Celsius}$

- 1.) Build the plate u,v coordinate system as follows.
  - Origin at hole 1.
  - u-axis defined by hole 1 and hole 9.
  - uv plane defined by symmetry plane parallel to plate's top surface through the center of the plate (offset by half of the plate's thickness).
  - Output the final hole coordinates in this coordinate system.
- 2.) Measure holes in the middle of the plate (eyeballing) as 2 circles with 4 probings each (probings always along coordinate system axis) -> 8 probings total. The 2 circles should be measured ~ 1 mm vertically separated. Evaluate as a cylinder. Intersect its axis with the plate's uv plane which is the symmetry plane parallel to the plate's top surface through the center of the plate (offset by half of the plate's thickness).
- 3.) Always measure in the sequence 1 - 32 clockwise, followed by 33 - 39.
- 4.) Measure the plate in 4 positions as described below. Output the coordinates for each position and the averaged values from all four positions. A total of four coordinate sets.
- 5.) Record temperature at the beginning and at the end of the measurements.

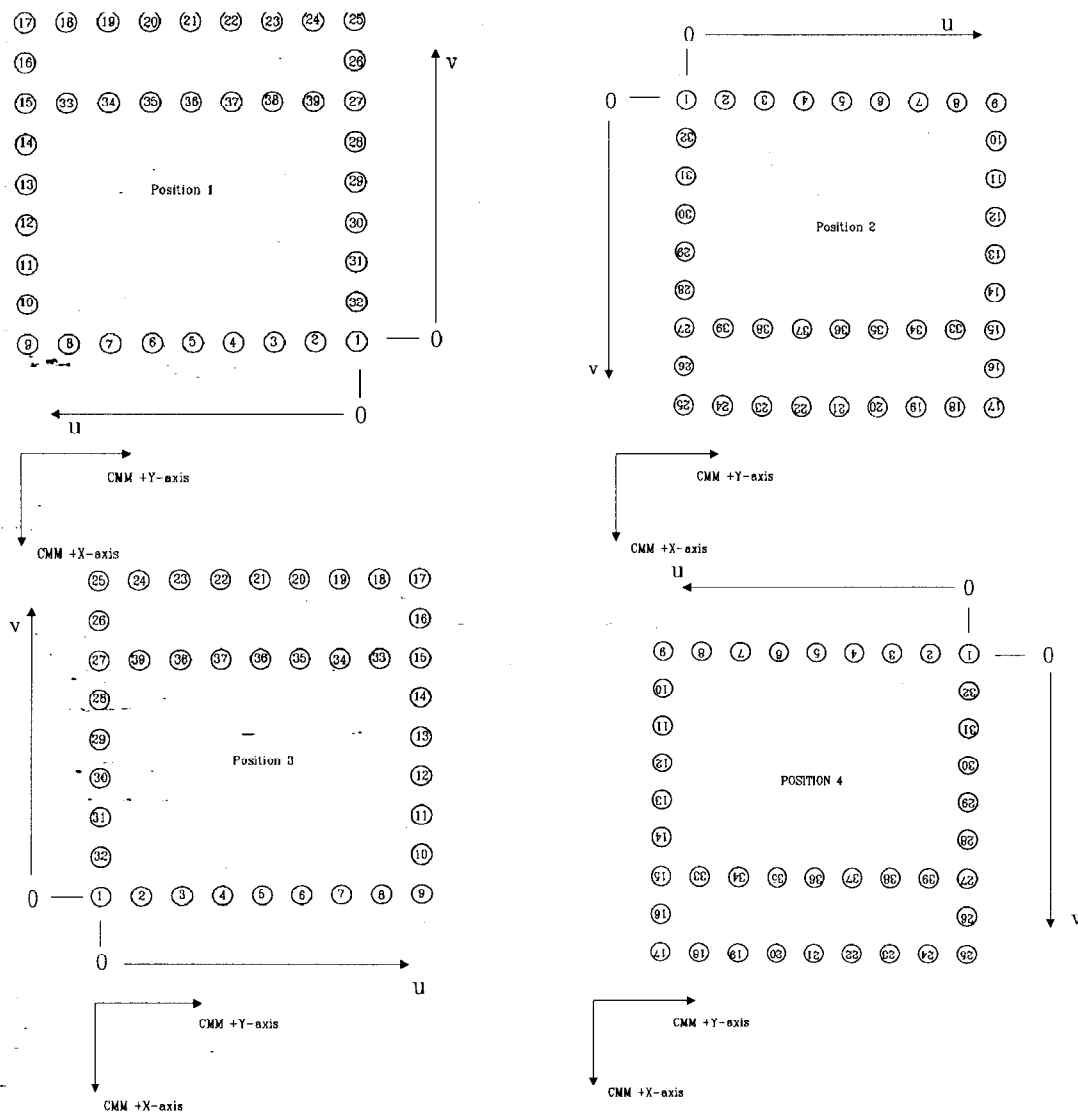


Figure 1: The four plate positions used for the swing round measurement procedure

## Calibration plate coordinate results (5-14-92)

These are the 2-dimensional values for the center circles projected into the symmetry plane (middle) of the plate. These are the values from the swing round method. Temperatur compensated for 20 Celsius.

PT. #	U [mm]	V [mm]
1	0.0000	0.0000
2	50.8028	-0.0076
3	101.6012	-0.0092
4	152.4033	-0.0111
5	203.1899	-0.0058
6	253.9789	-0.0025
7	304.7841	-0.0093
8	355.5738	0.0034
9	406.3747	0.0000
10	406.3658	50.8077
11	406.3500	101.5967
12	406.3304	152.4029
13	406.3155	203.2200
14	406.3044	254.0239
15	406.2888	304.8530
16	406.2715	355.6567
17	406.2475	406.4582
18	355.4582	406.4515
19	304.6602	406.4523
20	253.8724	406.4534
21	203.0745	406.4454
22	152.2888	406.4320
23	101.4904	406.4140
24	50.7047	406.4016
25	-0.0991	406.3938
26	-0.0713	355.5906
27	-0.0648	304.8067
28	-0.0390	254.0061
29	-0.0281	203.2034
30	-0.0247	152.3951
31	-0.0204	101.5917
32	-0.0088	50.7957
33	355.4864	304.8506
34	304.6826	304.8479
35	253.8925	304.8434
36	203.0969	304.8365
37	152.3097	304.8193
38	101.5164	304.8205
39	50.7308	304.8156

Boreplate calibration results from LEITZ PMM 12106							
					measurements		
	Temp. exp. coeff. for Alum.: 23.6 *10E-6/1 C						
	Position 1			4 Position average			
				no Temp comp			
	T(beginning)=19.50 C, T(end)=19.55, T(med.)=19.53						
			Me - Av				
	u(mm)	v(mm)	[μ]	[μ]	u(mm)	v(mm)	
ACYL1	0.0000	0.0000	0	0	0.0000	0.0000	
ACYL2	50.8033	-0.0079	1	0	50.8022	-0.0076	
ACYL3	101.6009	-0.0092	1	0	101.5999	-0.0092	
ACYL4	152.4026	-0.0112	1	0	152.4014	-0.0111	
ACYL5	203.1883	-0.0052	1	1	203.1874	-0.0058	
ACYL6	253.9759	-0.0022	0	0	253.9757	-0.0025	
ACYL7	304.7811	-0.0085	1	1	304.7803	-0.0093	
ACYL8	355.5701	0.0038	1	0	355.5694	0.0034	
ACYL9	406.3702	0.0000	1	0	406.3696	0.0000	
ACYL10	406.3616	50.8081	1	1	406.3607	50.8071	
ACYL11	406.3459	101.5958	1	0	406.3449	101.5954	
ACYL12	406.3265	152.4023	1	1	406.3253	152.4009	
ACYL13	406.3111	203.2183	1	1	406.3105	203.2174	
ACYL14	406.2997	254.0210	0	0	406.2993	254.0207	
ACYL15	406.2841	304.8501	0	1	406.2837	304.8492	
ACYL16	406.2660	355.6535	0	1	406.2664	355.6522	
ACYL17	406.2426	406.4533	0	0	406.2424	406.4531	
ACYL18	355.4534	406.4476	0	1	355.4538	406.4464	
ACYL19	304.6558	406.4481	-1	1	304.6564	406.4472	
ACYL20	253.8693	406.4495	0	1	253.8692	406.4483	
ACYL21	203.0714	406.4408	-1	0	203.0720	406.4403	
ACYL22	152.2871	406.4285	0	2	152.2869	406.4269	
ACYL23	101.4884	406.4095	-1	1	101.4892	406.4089	
ACYL24	50.7032	406.3952	-1	-1	50.7040	406.3965	
ACYL25	-0.0994	406.3885	0	0	-0.0991	406.3888	
ACYL26	-0.0720	355.5861	-1	0	-0.0713	355.5861	
ACYL27	-0.0648	304.8029	0	0	-0.0648	304.8028	
ACYL28	-0.0394	254.0017	0	-1	-0.0390	254.0029	
ACYL29	-0.0284	203.1999	0	-1	-0.0281	203.2009	
ACYL30	-0.0240	152.3918	1	-1	-0.0247	152.3932	
ACYL31	-0.0195	101.5893	1	-1	-0.0204	101.5904	
ACYL32	-0.0085	50.7930	0	-2	-0.0088	50.7951	
ACYL33	355.4823	304.8474	0	1	355.4819	304.8468	
ACYL34	304.6788	304.8459	0	2	304.6788	304.8441	
ACYL35	253.8893	304.8405	0	1	253.8894	304.8396	
ACYL36	203.0946	304.8336	0	1	203.0943	304.8327	
ACYL37	152.3077	304.8160	0	0	152.3078	304.8155	
ACYL38	101.5152	304.8171	0	0	101.5151	304.8167	
ACYL39	50.7295	304.8117	-1	0	50.7302	304.8118	



BOREPLA2.XLS

Position 2				
T(beginning)=19.45 C, T(end)=19.45, T(med.)=19.45				
	u(mm)	v(mm)	Me - Av	
			[μ]	[μ]
BCYL1	0.0000	0.0000	0	0
BCYL2	50.8020	-0.0075	0	0
BCYL3	101.6000	-0.0095	0	0
BCYL4	152.4016	-0.0111	0	0
BCYL5	203.1877	-0.0061	0	0
BCYL6	253.9759	-0.0027	0	0
BCYL7	304.7805	-0.0094	0	0
BCYL8	355.5698	0.0037	0	0
BCYL9	406.3701	0.0000	1	0
BCYL10	406.3611	50.8078	0	1
BCYL11	406.3450	101.5959	0	0
BCYL12	406.3257	152.4030	0	2
BCYL13	406.3110	203.2178	1	0
BCYL14	406.2996	254.0212	0	0
BCYL15	406.2840	304.8494	0	0
BCYL16	406.2672	355.6523	1	0
BCYL17	406.2438	406.4535	1	0
BCYL18	355.4555	406.4461	2	0
BCYL19	304.6579	406.4469	1	0
BCYL20	253.8703	406.4476	1	-1
BCYL21	203.0734	406.4399	1	0
BCYL22	152.2880	406.4260	1	-1
BCYL23	101.4904	406.4083	1	-1
BCYL24	50.7051	406.3968	1	0
BCYL25	-0.0980	406.3892	1	0
BCYL26	-0.0706	355.5860	1	0
BCYL27	-0.0646	304.8028	0	0
BCYL28	-0.0386	254.0030	0	0
BCYL29	-0.0276	203.2011	0	0
BCYL30	-0.0246	152.3935	0	0
BCYL31	-0.0204	101.5910	0	1
BCYL32	-0.0087	50.7961	0	1
BCYL33	355.4822	304.8466	0	0
BCYL34	304.6794	304.8435	1	-1
BCYL35	253.8899	304.8384	1	-1
BCYL36	203.0946	304.8317	0	-1
BCYL37	152.3081	304.8142	0	-1
BCYL38	101.5152	304.8156	0	-1
BCYL39	50.7304	304.8111	0	-1

## BOREPLA2.XLS

Position 3					
T(beginning)=19.1 C, T(end)=19.1, T(med.)=19.1					
		Me - Av			
u(mm)	v(mm)	[μ]	[μ]		
CCYL1	0.0000	0.0000	0	0	
CCYL2	50.8017	-0.0072	0	0	
CCYL3	101.5993	-0.0084	-1	1	
CCYL4	152.4006	-0.0101	-1	1	
CCYL5	203.1862	-0.0053	-1	1	
CCYL6	253.9748	-0.0017	-1	1	
CCYL7	304.7787	-0.0090	-2	0	
CCYL8	355.5676	0.0034	-2	0	
CCYL9	406.3676	0.0000	-2	0	
CCYL10	406.3583	50.8060	-2	-1	
CCYL11	406.3424	101.5943	-2	-1	
CCYL12	406.3227	152.3982	-3	-3	
CCYL13	406.3081	203.2154	-2	-2	
CCYL14	406.2971	254.0188	-2	-2	
CCYL15	406.2813	304.8467	-2	-2	
CCYL16	406.2644	355.6493	-2	-3	
CCYL17	406.2402	406.4501	-2	-3	
CCYL18	355.4519	406.4437	-2	-3	
CCYL19	304.6548	406.4449	-2	-2	
CCYL20	253.8680	406.4461	-1	-2	
CCYL21	203.0711	406.4384	-1	-2	
CCYL22	152.2861	406.4247	-1	-2	
CCYL23	101.4891	406.4070	0	-2	
CCYL24	50.7042	406.3946	0	-2	
CCYL25	-0.0990	406.3859	0	-3	
CCYL26	-0.0710	355.5837	0	-2	
CCYL27	-0.0647	304.8006	0	-2	
CCYL28	-0.0386	254.0017	0	-1	
CCYL29	-0.0277	203.2000	0	-1	
CCYL30	-0.0248	152.3930	0	0	
CCYL31	-0.0207	101.5902	0	0	
CCYL32	-0.0085	50.7955	0	0	
CCYL33	355.4800	304.8450	-2	-2	
CCYL34	304.6771	304.8424	-2	-2	
CCYL35	253.8879	304.8386	-1	-1	
CCYL36	203.0932	304.8314	-1	-1	
CCYL37	152.3070	304.8147	-1	-1	
CCYL38	101.5145	304.8156	-1	-1	
CCYL39	50.7304	304.8104	0	-1	



## BOREPLA2.XLS

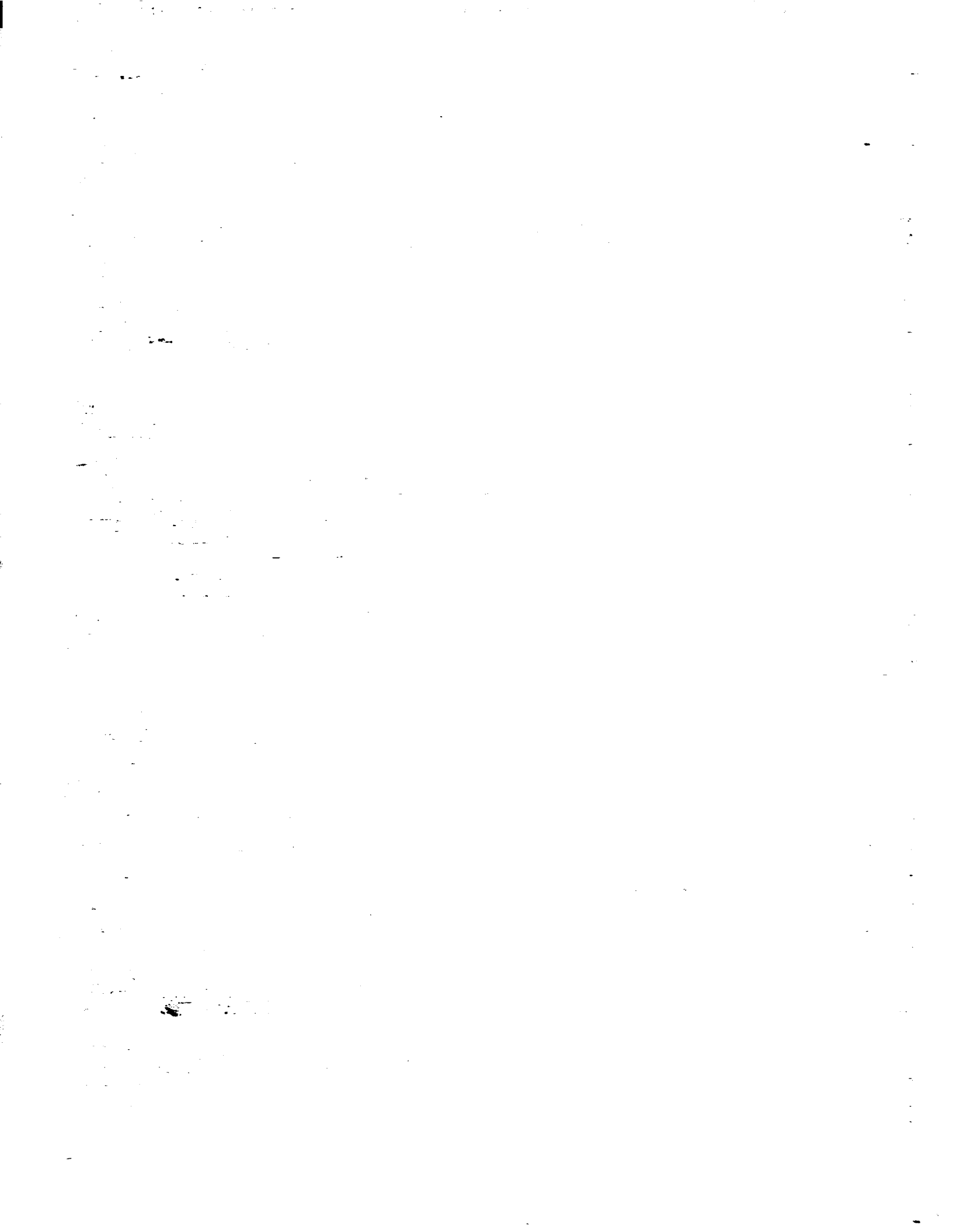
Position 1 Temperature compensated to 20 C						
	u(mm)	v(mm)	Me - Av 4 position average			
			[μ]	[μ]	u(mm)	v(mm)
ACYL1	0.0000	0.0000	0	0	0.0000	0.0000
ACYL2	50.8038	-0.0079	1	0	50.8028	-0.0076
ACYL3	101.6021	-0.0092	1	0	101.6012	-0.0092
ACYL4	152.4043	-0.0112	1	0	152.4033	-0.0111
ACYL5	203.1905	-0.0052	1	1	203.1899	-0.0058
ACYL6	253.9788	-0.0022	0	0	253.9789	-0.0025
ACYL7	304.7845	-0.0085	0	1	304.7841	-0.0093
ACYL8	355.5740	0.0038	0	0	355.5738	0.0034
ACYL9	406.3747	0.0000	0	0	406.3747	0.0000
ACYL10	406.3661	50.8086	0	1	406.3658	50.8077
ACYL11	406.3504	101.5969	0	0	406.3500	101.5967
ACYL12	406.3310	152.4040	1	1	406.3304	152.4029
ACYL13	406.3156	203.2206	0	1	406.3155	203.2200
ACYL14	406.3042	254.0238	0	0	406.3044	254.0239
ACYL15	406.2886	304.8535	0	1	406.2888	304.8530
ACYL16	406.2705	355.6574	-1	1	406.2715	355.6567
ACYL17	406.2471	406.4578	0	0	406.2475	406.4582
ACYL18	355.4573	406.4521	-1	1	355.4582	406.4515
ACYL19	304.6592	406.4526	-1	0	304.6602	406.4523
ACYL20	253.8721	406.4540	0	1	253.8724	406.4534
ACYL21	203.0736	406.4453	-1	0	203.0745	406.4454
ACYL22	152.2888	406.4330	0	1	152.2888	406.4320
ACYL23	101.4895	406.4140	-1	0	101.4904	406.4140
ACYL24	50.7037	406.3997	-1	-2	50.7047	406.4016
ACYL25	-0.0994	406.3930	0	-1	-0.0991	406.3938
ACYL26	-0.0720	355.5900	-1	-1	-0.0713	355.5906
ACYL27	-0.0648	304.8063	0	0	-0.0648	304.8067
ACYL28	-0.0394	254.0045	0	-2	-0.0390	254.0061
ACYL29	-0.0284	203.2022	0	-1	-0.0281	203.2034
ACYL30	-0.0240	152.3935	1	-2	-0.0247	152.3951
ACYL31	-0.0195	101.5904	1	-1	-0.0204	101.5917
ACYL32	-0.0085	50.7935	0	-2	-0.0088	50.7957
ACYL33	355.4862	304.8508	0	0	355.4864	304.8506
ACYL34	304.6821	304.8493	0	1	304.6826	304.8479
ACYL35	253.8922	304.8439	0	0	253.8925	304.8434
ACYL36	203.0969	304.8370	0	0	203.0969	304.8365
ACYL37	152.3094	304.8194	0	0	152.3097	304.8193
ACYL38	101.5163	304.8205	0	0	101.5164	304.8205
ACYL39	50.7300	304.8151	-1	-1	50.7308	304.8156





## BOREPLA2.XLS

Position 4 Temperature compensated to 20 C									
	u(mm)	v(mm)	Me - Av						
			[μ]	[μ]					
DCYL1	0.0000	0.0000	0	0					
DCYL2	50.8018	-0.0079	-1	0					
DCYL3	101.5999	-0.0099	-1	-1					
DCYL4	152.4016	-0.0119	-2	-1					
DCYL5	203.1882	-0.0067	-2	-1					
DCYL6	253.9774	-0.0034	-1	-1					
DCYL7	304.7822	-0.0105	-2	-1					
DCYL8	355.5717	0.0028	-2	-1					
DCYL9	406.3725	0.0000	-2	0					
DCYL10	406.3638	50.8068	-2	-1					
DCYL11	406.3482	101.5962	-2	0					
DCYL12	406.3283	152.4010	-2	-2					
DCYL13	406.3135	203.2191	-2	-1					
DCYL14	406.3028	254.0232	-2	-1					
DCYL15	406.2874	304.8519	-1	-1					
DCYL16	406.2700	355.6555	-2	-1					
DCYL17	406.2451	406.4574	-2	-1					
DCYL18	355.4560	406.4503	-2	-1					
DCYL19	304.6584	406.4507	-2	-2					
DCYL20	253.8706	406.4520	-2	-1					
DCYL21	203.0730	406.4441	-2	-1					
DCYL22	152.2872	406.4304	-2	-2					
DCYL23	101.4893	406.4126	-1	-1					
DCYL24	50.7039	406.4012	-1	0					
DCYL25	-0.1000	406.3934	-1	0					
DCYL26	-0.0714	355.5903	0	0					
DCYL27	-0.0651	304.8065	0	0					
DCYL28	-0.0394	254.0064	0	0					
DCYL29	-0.0288	203.2035	-1	0					
DCYL30	-0.0256	152.3951	-1	0					
DCYL31	-0.0211	101.5916	-1	0					
DCYL32	-0.0095	50.7959	-1	0					
DCYL33	355.4848	304.8494	-2	-1					
DCYL34	304.6814	304.8461	-1	-2					
DCYL35	253.8914	304.8423	-1	-1					
DCYL36	203.0959	304.8355	-1	-1					
DCYL37	152.3090	304.8186	-1	-1					
DCYL38	101.5160	304.8199	0	-1					
DCYL39	50.7307	304.8155	0	0					



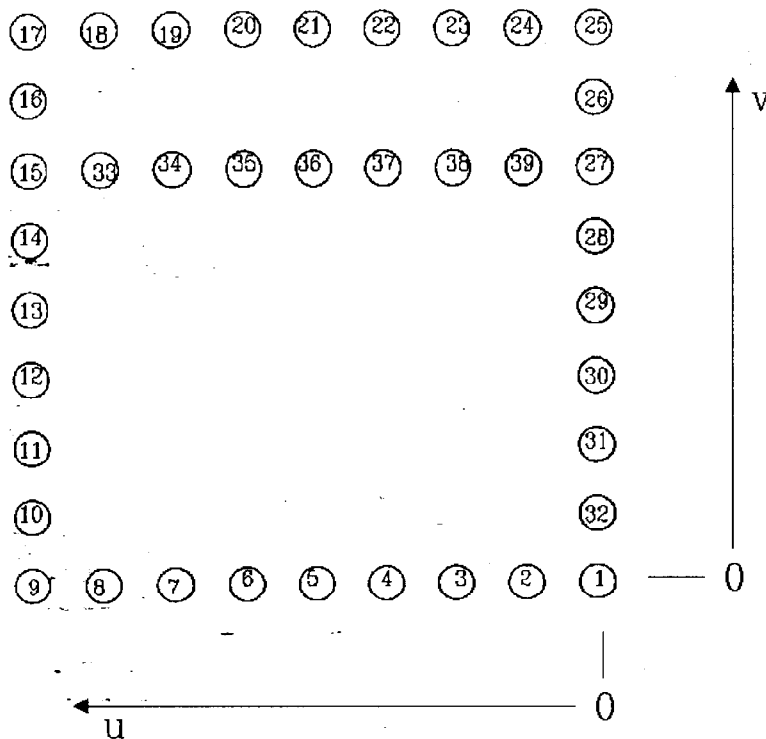




## APPENDIX C



## Calibration plate for MITUTOYO CMM



1.) Measure holes in the middle of the plate (eyeballing) as 2 circles with 4 probings each (probings always along coordinate system axis) -> 8 probings total. The 2 circles should be measured ~ 1 mm vertically separated. Evaluate as a cylinder. Intersect its axis with the symmetry plane parallel to the plate's top surface through the center of the plate (offset by half of the plate's thickness)

2.) Always measure in the sequence 1 - 32 clockwise and counterclockwise 32 - 1. Skip holes 33 - 39

3.) Pay close attention to the setup sheet from the PTB. The holes between the positions have to be lined up (more or less). Make sure the plate's u-axis is oriented as indicated. For position 31 and 32 line up edge with holes 5 and 21 from position 21 (22).

=====  
=====  
First data set => upstream volume  
=====

L1 = 103  
L21 = 100  
L22 = 0  
L31 = 103  
L32 = 103

=====  
| DATE | 4/27/92 | PROGRAM | H:BPCALIB1 |  
-----

+++ TIME: 8:18:38 +++  
+++ Plate Position: #1 (meas.11) U/S Area +++  
+++ Plate Temp= 20.7 +++ Beginning clockwise  
+++ Plate Temp= 20.8 +++ Beginning counterclockwise  
+++ Plate Temp= 20.9 +++ End

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]  
x = 3  
y = 114  
z = 468

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	-0.0017	-0.0007	0.6	0.3
02	50.8069	-0.0108	2.1	-2.8
03	101.6057	-0.0106	0.8	-0.2
04	152.4119	-0.0113	-1.3	-1.9
05	203.2008	-0.0079	-0.8	-1.8
06	253.9897	-0.0065	0.1	-0.5
07	304.7914	-0.0121	-0.9	-2.6
08	355.5852	0.0012	-2.2	-1.1
09	406.3863	0.0007	-0.7	-2.5
10	406.3789	50.8071	-0.9	-1.9
11	406.3591	101.5956	-1.8	-2.2
12	406.3404	152.4039	-5.5	-2.3
13	406.3151	203.2207	0.6	-3.4
14	406.3073	254.0254	-2.5	-1.0
15	406.2917	304.8592	-0.6	-2.0
16	406.2701	355.6624	0.7	-0.8
17	406.2467	406.4656	-0.6	-1.1
18	355.4528	406.4580	1.7	-0.8
19	304.6478	406.4563	0.7	0.7
20	253.8646	406.4580	0.7	-5.2
21	203.0647	406.4516	-0.5	-2.9
22	152.2769	406.4414	-0.5	-0.2
23	101.4752	406.4213	-1.1	-1.1
24	50.6864	406.4071	0.8	-0.5
25	-0.1201	406.4030	-0.9	-3.9
26	-0.0921	355.5979	1.8	-1.8
27	-0.0783	304.8146	-1.8	-0.3
28	-0.0514	254.0115	-0.3	-3.6
29	-0.0446	203.2097	0.3	-1.6
30	-0.0329	152.4026	-1.6	2.8

31	-0.0253	101.5986	-1.0	-2.1
32	-0.0084	50.8001	-0.2	-0.2

```
=====
| DATE           | 4/16/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      14:22:46 +++
+++ Plate Position: #2 (meas.12)   U/S Area +++
+++ Plate Temp= 22.2 +++
+++ Plate Temp= 22.3 +++ Beginning counterclockwise
+++ Plate Temp= 22.4 +++ End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 3
y = 114
z = 73
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0008	-0.0019	2.2	0.3
02	50.8035	-0.0098	2.9	1.7
03	101.6024	-0.0119	1.0	0.3
04	152.4070	-0.0125	0.5	-0.4
05	203.1967	-0.0077	0.3	-0.5
06	253.9873	-0.0062	-1.6	-1.2
07	304.7927	-0.0112	0.7	0.8
08	355.5855	0.0019	-1.3	0.7
09	406.3893	-0.0013	1.0	-0.1
10	406.3805	50.8069	0.0	0.7
11	406.3610	101.5958	0.1	-0.9
12	406.3398	152.4021	1.0	-2.8
13	406.3195	203.2197	0.2	-0.1
14	406.3109	254.0259	-0.1	1.3
15	406.2931	304.8581	1.0	1.5
16	406.2718	355.6612	0.3	0.1
17	406.2482	406.4631	-0.7	0.6
18	355.4526	406.4548	1.2	-0.9
19	304.6482	406.4555	-2.7	1.5
20	253.8626	406.4566	-0.6	0.6
21	203.0614	406.4505	-2.3	0.8
22	152.2739	406.4382	1.7	0.6
23	101.4709	406.4187	2.7	0.8
24	50.6813	406.4051	-1.9	0.2
25	-0.1233	406.4001	2.4	1.2
26	-0.0937	355.5967	0.1	0.2
27	-0.0804	304.8119	-2.3	-0.4
28	-0.0543	254.0081	-0.6	2.0
29	-0.0454	203.2047	-0.9	0.6
30	-0.0360	152.3967	0.5	0.4
31	-0.0285	101.5927	-2.2	-0.3
32	-0.0126	50.7949	2.3	0.1

```
=====
| DATE           | 4/13/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      13:17:40 +++
+++ Plate Position: #3 (meas.21)   U/S Area +++
+++ Plate Temp= 20.3 +++
+++ Plate Temp= 20.5 +++   Beginning counterclockwise
+++ Plate Temp= 20.6 +++   End
```

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]

```
x = 26
y = 197
z = 191
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0037	-0.0009	-0.2	1.9
02	50.8066	-0.0056	-0.1	2.2
03	101.6056	-0.0073	2.0	4.0
04	152.4076	-0.0083	1.2	2.8
05	203.1951	-0.0033	-0.5	4.3
06	253.9844	-0.0002	-0.3	1.0
07	304.7886	-0.0074	-0.6	0.7
08	355.5786	0.0052	0.0	1.4
09	406.3779	-0.0002	0.6	2.8
10	406.3682	50.8097	-3.0	2.3
11	406.3506	101.5984	-1.6	3.3
12	406.3341	152.4050	7.4	0.4
13	406.3170	203.2253	-1.6	1.6
14	406.3160	254.0289	2.1	-0.4
15	406.3037	304.8616	-2.1	1.6
16	406.2835	355.6659	1.7	-1.7
17	406.2615	406.4694	-1.6	0.2
18	355.4772	406.4642	0.8	-0.4
19	304.6758	406.4649	-0.1	0.5
20	253.8898	406.4665	-2.8	1.1
21	203.0958	406.4588	0.9	2.0
22	152.3056	406.4459	-1.3	0.6
23	101.5036	406.4267	-1.9	3.3
24	50.7169	406.4124	0.5	0.5
25	-0.0900	406.4060	1.4	2.7
26	-0.0637	355.6000	1.5	1.3
27	-0.0531	304.8157	1.4	-0.1
28	-0.0291	254.0111	-1.6	0.0
29	-0.0286	203.2092	1.1	0.8
30	-0.0249	152.4002	0.7	-0.3
31	-0.0196	101.5941	-0.7	-0.2
32	-0.0080	50.7957	0.0	1.2

```
=====
| DATE           | 4/13/92           | PROGRAM           | H:BPCALIB1       |
|-----|-----|-----|-----|

```

```
+++ TIME:      14:23:39 +++
+++ Plate Position: #4 (meas.22)   U/S Area +++
+++ Plate Temp= 20.5 +++
+++ Plate Temp= 20.6 +++   Beginning counterclockwise
+++ Plate Temp= 20.4 +++   End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 26
y = 97
z = 191
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	50.0005	-0.0015	-0.8	2.7
02	50.8005	-0.0063	0.0	-0.9
03	101.5998	-0.0070	0.0	-2.1
04	152.4039	-0.0088	0.5	-0.5
05	203.1898	-0.0027	-1.2	-1.7
06	253.9782	-0.0002	-2.5	-0.9
07	304.7825	-0.0081	-1.8	1.5
08	355.5734	0.0055	-1.3	-0.7
09	406.3733	0.0008	0.5	-2.3
10	406.3659	50.8088	1.0	-0.6
11	406.3451	101.5962	1.4	-2.0
12	406.3250	152.4017	0.8	0.2
13	406.3110	203.2219	0.8	-0.1
14	406.3095	254.0247	1.0	-1.7
15	406.2954	304.8554	1.7	-0.7
16	406.2779	355.6592	0.3	0.6
17	406.2570	406.4615	1.0	0.7
18	355.4728	406.4550	1.4	-0.1
19	304.6714	406.4572	1.5	-0.1
20	253.8845	406.4588	0.0	0.9
21	203.0874	406.4499	0.9	-3.0
22	152.3010	406.4371	1.4	0.6
23	101.4987	406.4178	0.4	0.4
24	50.7112	406.4037	0.6	-1.1
25	-0.0947	406.3962	-1.3	0.1
26	-0.0680	355.5934	-0.7	1.2
27	-0.0610	304.8092	-1.9	1.6
28	-0.0353	254.0057	-0.5	-0.1
29	-0.0344	203.2056	0.0	2.2
30	-0.0308	152.3961	-0.4	0.5
31	-0.0256	101.5929	0.5	0.2
32	-0.0134	50.7958	0.8	0.5

```
=====
| DATE           | 4/30/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      8:16:49 +++
+++ Plate Position: #5 (meas.31)   U/S Area +++
+++ Plate Temp= 21.4 +++
+++ Plate Temp= 21.4 +++ Beginning counterclockwise
+++ Plate Temp= 21.4 +++ End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 310
y = 110
z = 170
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	-0.0003	0.0018	-0.3	-1.3
02	50.8021	-0.0108	2.5	0.6
03	101.5971	-0.0167	-0.9	-1.2
04	152.4011	-0.0224	-0.4	0.2
05	203.1885	-0.0121	-0.2	-2.6
06	253.9803	-0.0096	-0.4	-0.9
07	304.7872	-0.0184	-0.9	-0.6
08	355.5781	-0.0012	-0.1	-0.2
09	406.3800	0.0008	0.5	0.2
10	406.3769	50.8097	-0.8	-0.5
11	406.3652	101.5990	-1.0	0.7
12	406.3515	152.4071	0.1	-1.8
13	406.3386	203.2255	0.2	0.1
14	406.3340	254.0294	0.5	0.6
15	406.3236	304.8617	1.1	0.3
16	406.3094	355.6645	1.0	1.6
17	406.2916	406.4660	0.4	0.3
18	355.5018	406.4536	-0.3	0.2
19	304.7045	406.4479	1.7	0.1
20	253.9169	406.4502	0.8	-0.4
21	203.1165	406.4402	0.4	1.2
22	152.3303	406.4244	-0.8	2.0
23	101.5327	406.4094	-0.3	0.1
24	50.7487	406.3981	-2.1	2.6
25	-0.0540	406.3961	0.3	0.7
26	-0.0321	355.5939	-1.8	1.8
27	-0.0300	304.8109	0.3	-0.2
28	-0.0109	254.0090	-1.2	1.0
29	-0.0096	203.2077	-0.1	1.9
30	-0.0072	152.3986	-3.0	0.9
31	-0.0108	101.5937	-0.8	1.7
32	-0.0051	50.7985	-0.6	0.8



```
=====
| DATE           | 4/30/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      10:47:10 +++
+++ Plate Position: #6 (meas.32)   U/S Area +++
+++ Plate Temp= 21.4 +++
+++ Plate Temp= 21.4 +++   Beginning counterclockwise
+++ Plate Temp= 21.4 +++   End
```

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]

```
x = 100
y = 110
z = 170
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0002	0.0000	0.4	0.6
02	50.8030	-0.0088	-1.5	-0.8
03	101.6014	-0.0138	-1.3	-0.3
04	152.4050	-0.0162	-0.6	-1.1
05	203.1921	-0.0107	-1.3	0.9
06	253.9820	-0.0084	-2.3	-0.3
07	304.7881	-0.0132	-0.4	-0.1
08	355.5804	-0.0004	0.2	-0.8
09	406.3819	0.0007	-0.2	-0.5
10	406.3789	50.8094	0.9	-0.9
11	406.3686	101.5989	-0.8	0.3
12	406.3552	152.4054	-0.4	-0.1
13	406.3449	203.2226	-0.1	-0.9
14	406.3408	254.0305	2.2	1.4
15	406.3293	304.8616	-1.0	-1.6
16	406.3171	355.6659	0.4	-2.5
17	406.3002	406.4681	-1.5	-3.7
18	355.5095	406.4586	0.0	-0.3
19	304.7103	406.4572	1.1	-2.7
20	253.9241	406.4551	-0.7	-0.4
21	203.1259	406.4466	-0.1	0.5
22	152.3396	406.4332	0.1	-1.0
23	101.5418	406.4133	-0.7	-0.1
24	50.7558	406.4016	-0.1	-1.2
25	-0.0492	406.3974	1.2	-0.9
26	-0.0280	355.5940	-0.3	-2.1
27	-0.0271	304.8107	-0.6	-0.6
28	-0.0091	254.0068	-0.8	-2.1
29	-0.0057	203.2049	0.7	-0.4
30	-0.0077	152.3963	0.9	-1.1
31	-0.0106	101.5918	-0.9	-1.0
32	-0.0052	50.7960	-0.1	-0.1

=====  
=====  
Second data set => downstream volume  
=====  
=====

L1 = 103  
L21 = 100  
L22 = 0  
L31 = 103  
L32 = 103

=====  
| DATE | 4/27/92 | PROGRAM | H:BPCALIB1 |  
-----

+++ TIME: 9:29:10 +++  
+++ Plate Position: #7 (meas.11) D/S Area +++  
+++ Plate Temp= 21.0 +++ Beginning clockwise  
+++ Plate Temp= 21.1 +++ Beginning counterclockwise  
+++ Plate Temp= 21.2 +++ End

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]  
x = 594  
y = 114  
z = 472

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0006	0.0021	-3.8	0.6
02	50.8046	-0.0026	-2.1	-3.8
03	101.6091	-0.0018	4.2	0.6
04	152.4111	-0.0068	-0.1	-1.3
05	203.1943	-0.0009	0.8	-1.2
06	253.9867	-0.0000	1.7	-1.1
07	304.7940	-0.0076	1.3	0.7
08	355.5820	0.0035	-2.7	0.2
09	406.3840	-0.0001	-1.7	-1.4
10	406.3728	50.8074	-0.3	-1.1
11	406.3515	101.5972	-1.7	-3.0
12	406.3281	152.4034	1.3	-0.2
13	406.3030	203.2221	-1.8	-0.9
14	406.2958	254.0268	-1.8	-0.1
15	406.2779	304.8599	1.8	-1.1
16	406.2513	355.6638	0.3	-1.6
17	406.2257	406.4660	-0.3	-0.8
18	355.4352	406.4629	2.1	-1.1
19	304.6389	406.4633	2.9	-1.5
20	253.8491	406.4654	-1.3	0.8
21	203.0434	406.4589	-1.4	-1.5
22	152.2613	406.4477	1.4	1.0
23	101.4631	406.4299	0.1	-1.0
24	50.6691	406.4147	-1.8	1.0
25	-0.1387	406.4065	-0.5	0.4
26	-0.1059	355.6026	0.8	-1.6
27	-0.0903	304.8187	-2.4	-1.0
28	-0.0621	254.0132	1.3	-2.3
29	-0.0530	203.2108	1.5	-0.6

30	-0.0398	152.4016	-0.9	-2.1
31	-0.0290	101.5965	-1.7	-0.7
32	-0.0113	50.7998	-1.9	0.5

```
=====
| DATE           | 4/16/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      12:59:11 +++
+++ Plate Position: #8 (meas.12) D/S Area +++
+++ Plate Temp= 22.1 +++ Beginning clockwise
+++ Plate Temp= 22.2 +++ Beginning counterclockwise
+++ Plate Temp= 22.2 +++ End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 605
y = 114
z = 85
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	-0.0023	-0.0008	3.5	1.2
02	50.8040	-0.0052	0.0	1.1
03	101.6076	-0.0055	-1.8	0.8
04	152.4100	-0.0080	-3.4	0.2
05	203.1956	-0.0032	-2.0	0.9
06	253.9889	-0.0021	-1.7	0.5
07	304.7979	-0.0098	-1.6	0.5
08	355.5875	0.0033	-1.6	0.6
09	406.3920	0.0002	-0.8	0.2
10	406.3813	50.8073	1.9	-0.4
11	406.3607	101.5957	-0.9	0.8
12	406.3367	152.4030	0.6	1.6
13	406.3168	203.2209	0.9	0.6
14	406.3064	254.0268	-0.5	2.1
15	406.2890	304.8590	0.0	1.4
16	406.2665	355.6617	0.3	1.7
17	406.2422	406.4631	2.0	-0.8
18	355.4496	406.4579	0.2	1.9
19	304.6512	406.4587	1.8	0.2
20	253.8596	406.4631	1.1	0.6
21	203.0525	406.4550	0.9	0.3
22	152.2697	406.4432	-1.6	0.0
23	101.4700	406.4241	-0.9	1.6
24	50.6795	406.4102	1.4	0.5
25	-0.1307	406.4019	-1.7	1.8
26	-0.1010	355.5987	0.9	0.6
27	-0.0861	304.8138	-0.8	-0.3
28	-0.0586	254.0105	2.5	-0.5
29	-0.0477	203.2064	0.4	1.5
30	-0.0373	152.3994	0.1	-1.2
31	-0.0294	101.5943	-1.7	1.3
32	-0.0118	50.7961	-1.0	0.6

```
=====
| DATE           | 4/13/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      9:55:36 +++
+++ Plate Position: #9 (meas.21) D/S Area +++
+++ Plate Temp= 20.7 +++ Beginning clockwise
+++ Plate Temp= 20.3 +++ Beginning counterclockwise
+++ Plate Temp= 20.1 +++ End
```

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]

```
x = 586
y = 197
z = 191
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0010	0.0029	2.2	-7.3
02	50.7999	-0.0050	6.5	-8.7
03	101.6150	-0.0034	-9.1	-5.6
04	152.4056	-0.0073	4.1	-5.5
05	203.1885	-0.0018	0.6	-7.3
06	253.9797	0.0025	2.7	-4.9
07	304.7867	-0.0048	2.7	-4.8
08	355.5752	0.0087	1.2	-6.0
09	406.3760	0.0052	2.2	-5.7
10	406.3662	50.8131	2.0	-4.5
11	406.3499	101.6020	2.8	-2.6
12	406.3345	152.4091	11.4	-3.3
13	406.3162	203.2289	2.0	-4.3
14	406.3171	254.0331	1.5	-5.2
15	406.3073	304.8651	-0.5	-3.2
16	406.2876	355.6696	-2.7	-2.5
17	406.2651	406.4725	-0.9	-2.7
18	355.4762	406.4661	-4.1	-1.2
19	304.6780	406.4679	-1.4	-3.9
20	253.8902	406.4682	-0.1	-0.4
21	203.0859	406.4591	1.7	-1.8
22	152.3093	406.4470	-1.0	-1.0
23	101.5087	406.4289	-1.8	0.5
24	50.7193	406.4156	-1.8	-0.6
25	-0.0835	406.4084	0.2	1.6
26	-0.0561	355.6041	-1.2	0.5
27	-0.0471	304.8196	-1.2	2.5
28	-0.0248	254.0154	-0.4	-0.1
29	-0.0262	203.2134	-4.2	-0.7
30	-0.0240	152.4042	-2.9	0.6
31	-0.0198	101.5987	-7.2	-0.7
32	-0.0079	50.8014	-1.2	-1.9

```
=====
| DATE           | 4/13/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:       7:57:31 +++
+++ Plate Position: #10 (meas.22) D/S Area +++
+++ Plate Temp= 21.5 +++ Beginning clockwise
+++ Plate Temp= 20.2 +++ Beginning counterclockwise
+++ Plate Temp= 20.6 +++ End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 586
y = 97
z = 191
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0004	-0.0038	1.5	-7.7
02	50.8044	-0.0080	-0.4	-3.8
03	101.6052	-0.0073	0.0	-1.1
04	152.4072	-0.0088	0.0	1.3
05	203.1934	-0.0022	0.8	1.2
06	253.9847	0.0020	-1.6	0.3
07	304.7944	-0.0033	-1.5	1.0
08	355.5828	-0.0108	-0.6	1.3
09	406.3855	0.0070	0.3	0.1
10	406.3750	50.8153	-1.8	-0.2
11	406.3576	101.6042	-2.1	-1.5
12	406.3382	152.4105	-3.5	-0.1
13	406.3224	203.2299	2.9	-0.4
14	406.3211	254.0342	1.1	-1.5
15	406.3070	304.8656	1.0	-0.6
16	406.2880	355.6695	0.3	-0.5
17	406.2674	406.4726	2.1	-1.2
18	355.4762	406.4650	-1.0	-0.7
19	304.6798	406.4657	-0.2	-0.4
20	253.8898	406.4657	-1.3	0.1
21	203.0862	406.4571	0.5	-1.4
22	152.3031	406.4439	0.3	0.3
23	101.5039	406.4246	-0.7	-1.2
24	50.7113	406.4097	0.6	-2.0
25	-0.0925	406.4009	1.3	-0.9
26	-0.0653	355.5970	2.8	0.8
27	-0.0579	304.8119	-0.1	-2.0
28	-0.0342	254.0075	0.5	-0.7
29	-0.0341	203.2070	-1.5	-0.9
30	-0.0290	152.3966	-0.5	-0.2
31	-0.0256	101.5912	-2.4	-1.1
32	-0.0114	50.7944	-0.8	-0.1

```
=====
| DATE           | 4/27/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      11:07:31 +++
+++ Plate Position: #11 (meas.31) D/S Area +++
+++ Plate Temp= 21.5 +++ Beginning clockwise
+++ Plate Temp= 21.6 +++ Beginning counterclockwise
+++ Plate Temp= 21.7 +++ End
```

```
Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]
x = 900
y = 112
z = 170
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0002	-0.0035	0.0	3.2
02	50.8036	-0.0151	0.0	5.0
03	101.5994	-0.0175	-0.4	3.1
04	152.4032	-0.0247	1.1	1.7
05	203.1908	-0.0158	0.6	-0.8
06	253.9827	-0.0118	-2.3	1.6
07	304.7884	-0.0198	1.4	2.2
08	355.5793	-0.0029	1.0	0.1
09	406.3818	-0.0011	1.8	0.5
10	406.3770	50.8084	0.3	4.1
11	406.3677	101.5968	1.7	0.2
12	406.3523	152.4048	2.2	3.0
13	406.3399	203.2225	1.4	0.1
14	406.3362	254.0269	-1.6	1.6
15	406.3250	304.8590	1.2	-0.2
16	406.3111	355.6629	-1.1	3.8
17	406.2940	406.4647	1.5	4.3
18	355.5033	406.4520	0.4	2.8
19	304.7057	406.4462	1.7	2.7
20	253.9174	406.4479	2.4	5.1
21	203.1177	406.4379	1.0	2.8
22	152.3332	406.4208	-0.5	1.3
23	101.5333	406.4049	-0.6	2.3
24	50.7495	406.3940	-0.5	0.9
25	-0.0522	406.3932	0.9	3.3
26	-0.0305	355.5894	0.3	-0.8
27	-0.0280	304.8061	0.6	1.3
28	-0.0089	254.0043	0.7	2.0
29	-0.0065	203.2033	-0.3	1.1
30	-0.0068	152.3944	-0.3	1.4
31	-0.0078	101.5924	-1.1	0.5
32	-0.0032	50.7944	-1.0	0.6

```
=====
| DATE           | 4/30/92           | PROGRAM           | H:BPCALIB1       |
=====
```

```
+++ TIME:      15:41:43 +++
+++ Plate Position: #12 (meas.32) D/S Area +++
+++ Plate Temp= 21.4 +++ Beginning clockwise
+++ Plate Temp= 21.4 +++ Beginning counterclockwise
+++ Plate Temp= 21.4 +++ End
```

Pt01 in reference to CMM kinematic axis system (CMM volume) in [mm]

```
x = 690
y = 110
z = 170
```

(dU and dV are Deltas between clockwise and counterclockwise measurements)

pt	U avg [millimeters]	V avg	dU [microns]	dV
01	0.0009	-0.0002	0.9	-0.3
02	50.8045	-0.0091	-1.3	-1.7
03	101.6039	-0.0142	-0.5	-1.2
04	152.4054	-0.0103	-3.6	12.0
05	203.1936	-0.0093	1.5	-0.8
06	253.9827	-0.0075	-0.9	0.3
07	304.7899	-0.0137	-0.3	-0.6
08	355.5830	-0.0000	-0.5	-0.4
09	406.3841	0.0013	0.4	-1.2
10	406.3806	50.8103	-1.0	-0.2
11	406.3726	101.5993	4.3	0.6
12	406.3608	152.4065	7.9	0.3
13	406.3484	203.2233	3.2	0.1
14	406.3424	254.0299	-2.4	-0.2
15	406.3322	304.8635	1.5	0.0
16	406.3202	355.6672	1.3	0.9
17	406.3037	406.4702	0.0	0.5
18	355.5126	406.4600	0.4	1.7
19	304.7136	406.4574	0.6	0.5
20	253.9262	406.4573	0.2	-0.9
21	203.1292	406.4487	0.7	-1.1
22	152.3443	406.4338	0.1	0.9
23	101.5452	406.4152	0.4	0.1
24	50.7591	406.4028	1.7	-0.1
25	-0.0465	406.3987	1.2	-1.5
26	-0.0260	355.5965	-0.1	-0.1
27	-0.0236	304.8116	0.0	-0.2
28	-0.0057	254.0073	-0.2	0.1
29	-0.0034	203.2053	0.3	-1.0
30	-0.0058	152.3974	-1.9	0.9
31	-0.0068	101.5927	1.1	-0.7
32	-0.0018	50.7965	1.3	0.1





## APPENDIX D

## MIT\_CHK2.XLS

Plate calibration values			Pos #2		UPSTREAM AREA		
Pt	X(mm)	Y(mm)	X(mm)	Y(mm)	Delta X	DeltaY	
					in microns		
1	0.0000	0.0000	-0.0004	0.0014	0	-1	BEFORE
2	50.8028	-0.0076	50.8009	-0.0073	2	0	
3	101.6012	-0.0092	101.5973	-0.0097	4	1	
4	152.4033	-0.0111	152.3989	-0.0095	4	-2	
5	203.1899	-0.0058	203.1848	-0.0046	5	-1	
6	253.9789	-0.0025	253.9750	-0.0038	4	1	
7	304.7841	-0.0093	304.7760	-0.0098	8	1	
8	355.5738	0.0034	355.5655	0.0045	8	-1	
9	406.3747	0.0000	406.3658	0.0009	9	-1	
10	406.3658	50.8077	406.3558	50.8063	10	1	
11	406.3500	101.5967	406.3382	101.5935	12	3	
12	406.3304	152.4029	406.3164	152.3963	14	7	
13	406.3155	203.2200	406.2934	203.2120	22	8	
14	406.3044	254.0239	406.2867	254.0158	18	8	
15	406.2888	304.8530	406.2712	304.8441	18	9	
16	406.2715	355.6567	406.2495	355.6456	22	11	
17	406.2475	406.4582	406.2255	406.4447	22	13	
18	355.4582	406.4515	355.4315	406.4360	27	16	
19	304.6602	406.4523	304.6313	406.4372	29	15	
20	253.8724	406.4534	253.8477	406.4384	25	15	
21	203.0745	406.4454	203.0491	406.4311	25	14	
22	152.2888	406.4320	152.2653	406.4201	24	12	
23	101.4904	406.4140	101.4667	406.3994	24	15	
24	50.7047	406.4016	50.6810	406.3853	24	16	
25	-0.0991	406.3938	-0.1214	406.3790	22	15	
26	-0.0713	355.5906	-0.0906	355.5792	19	11	
27	-0.0648	304.8067	-0.0759	304.7980	11	9	
28	-0.0390	254.0061	-0.0522	253.9961	13	10	
29	-0.0281	203.2034	-0.0427	203.1962	15	7	
30	-0.0247	152.3951	-0.0330	152.3892	8	6	
31	-0.0204	101.5917	-0.0258	101.5887	5	3	
32	-0.0088	50.7900	-0.0094	50.7934	1	-3	
				Temperature and			
Plate calibration values			Pos #2		Squareness XY corrected (-0.000057 rad)		
Pt	X(mm)	Y(mm)	X(mm)	Y(mm)	Delta X	DeltaY	
					in microns		
1	0.0000	0.0000	-0.0004	0.0014	0	-1	AFTER
2	50.8028	-0.0076	50.8009	-0.0073	2	0	
3	101.6012	-0.0092	101.5973	-0.0097	4	1	
4	152.4033	-0.0111	152.3989	-0.0095	4	-2	
5	203.1899	-0.0058	203.1848	-0.0046	5	-1	
6	253.9789	-0.0025	253.9750	-0.0038	4	1	
7	304.7841	-0.0093	304.7760	-0.0098	8	1	

## MIT\_CHK2.XLS

8	355.5738	0.0034	355.5655	0.0045	8	-1		
9	406.3747	0.0000	406.3658	0.0009	9	-1		
10	406.3658	50.8077	406.3587	50.8063	7	0		
11	406.3500	101.5967	406.3440	101.5935	6	0		
12	406.3304	152.4029	406.3251	152.3963	5	2		
13	406.3155	203.2200	406.3050	203.2120	11	2		
14	406.3044	254.0239	406.3012	254.0158	3	1		
15	406.2888	304.8530	406.2886	304.8441	0	0		
16	406.2715	355.6567	406.2698	355.6456	2	1		
17	406.2475	406.4582	406.2487	406.4447	-1	2		
18	355.4582	406.4515	355.4547	406.4360	4	4		
19	304.8602	406.4523	304.6545	406.4372	6	4		
20	253.8724	406.4534	253.8709	406.4384	2	4		
21	203.0745	406.4454	203.0723	406.4311	2	3		
22	152.2888	406.4320	152.2885	406.4201	0	1		
23	101.4904	406.4140	101.4899	406.3994	1	3		
24	50.7047	406.4016	50.7042	406.3853	1	5		
25	-0.0991	406.3938	-0.0982	406.3790	-1	3		
26	-0.0713	355.5906	-0.0703	355.5792	-1	1		
27	-0.0648	304.8067	-0.0585	304.7980	-6	0		
28	-0.0390	254.0061	-0.0377	253.9961	-1	3		
29	-0.0281	203.2034	-0.0311	203.1962	3	2		
30	-0.0247	152.3951	-0.0243	152.3892	0	2		
31	-0.0204	101.5917	-0.0200	101.5887	0	0		
32	-0.0088	50.7900	-0.0065	50.7934	-2	-5		

Plate calibration values			Pos #3	UPSTREAM AREA			
Pt	X(mm)	Z(mm)	X(mm)	Z(mm)	Delta X	Delta Z	
					in microns		
1	0.0000	0.0000	0.0037	-0.0009	-4	1	BEFORE
2	50.8028	-0.0076	50.8066	-0.0056	-4	-2	
3	101.6012	-0.0092	101.6056	-0.0073	-4	-2	
4	152.4033	-0.0111	152.4076	-0.0083	-4	-3	
5	203.1899	-0.0058	203.1951	-0.0033	-5	-3	
6	253.9789	-0.0025	253.9844	-0.0002	-5	-2	
7	304.7841	-0.0093	304.7886	-0.0074	-4	-2	
8	355.5738	0.0034	355.5786	0.0052	-5	-2	
9	406.3747	0.0000	406.3779	-0.0002	-3	0	
10	406.3658	50.8077	406.3682	50.8097	-2	-2	
11	406.3500	101.5967	406.3506	101.5984	-1	-2	
12	406.3304	152.4029	406.3341	152.4050	-4	-2	
13	406.3155	203.2200	406.3170	203.2253	-2	-5	
14	406.3044	254.0239	406.3160	254.0289	-12	-5	
15	406.2888	304.8530	406.3037	304.8616	-15	-9	
16	406.2715	355.6567	406.2835	355.6659	-12	-9	
17	406.2475	406.4582	406.2615	406.4694	-14	-11	
18	355.4582	406.4515	355.4772	406.4642	-19	-13	
19	304.6602	406.4523	304.6758	406.4649	-16	-13	
20	253.8724	406.4534	253.8898	406.4665	-17	-13	
21	203.0745	406.4454	203.0958	406.4588	-21	-13	
22	152.2888	406.4320	152.3056	406.4459	-17	-14	
23	101.4904	406.4140	101.5036	406.4267	-13	-13	
24	50.7047	406.4016	50.7169	406.4124	-12	-11	
25	-0.0991	406.3938	-0.0900	406.4060	-9	-12	
26	-0.0713	355.5906	-0.0637	355.6000	-8	-9	
27	-0.0648	304.8067	-0.0531	304.8157	-12	-9	
28	-0.0390	254.0061	-0.0291	254.0111	-10	-5	
29	-0.0281	203.2034	-0.0286	203.2092	1	-6	
30	-0.0247	152.3951	-0.0249	152.4002	0	-5	
31	-0.0204	101.5917	-0.0196	101.5941	-1	-2	
32	-0.0088	50.7900	-0.0080	50.7957	-1	-6	
				Temperature and			
Plate calibration values			Pos #3	Squareness XZ corrected (0.000035 rad)			
Pt	X(mm)	Z(mm)	X(mm)	Z(mm)	Delta X	Delta Z	
					in microns		
1	0.0000	0.0000	0.0037	-0.0009	-4	1	AFTER
2	50.8028	-0.0076	50.8066	-0.0056	-4	-2	
3	101.6012	-0.0092	101.6056	-0.0073	-4	-2	
4	152.4033	-0.0111	152.4076	-0.0083	-4	-3	
5	203.1899	-0.0058	203.1951	-0.0033	-5	-3	
6	253.9789	-0.0025	253.9844	-0.0002	-6	-2	
7	304.7841	-0.0093	304.7886	-0.0074	-5	-2	

## MIT\_CHK3.XLS

8	355.5738	0.0034	355.5786	0.0052	-5	-2		
9	406.3747	0.0000	406.3779	-0.0002	-3	0		
10	406.3658	50.8077	406.3664	50.8097	-1	-1		
11	406.3500	101.5967	406.3470	101.5984	3	1		
12	406.3304	152.4029	406.3288	152.4050	2	2		
13	406.3155	203.2200	406.3099	203.2253	6	0		
14	406.3044	254.0239	406.3071	254.0289	-3	2		
15	406.2888	304.8530	406.2930	304.8616	-4	0		
16	406.2715	355.6567	406.2711	355.6659	0	1		
17	406.2475	406.4582	406.2473	406.4694	0	0		
18	355.4582	406.4515	355.4630	406.4642	-5	-1		
19	304.6682	406.4523	304.6616	406.4649	-1	-1		
20	253.8724	406.4534	253.8756	406.4665	-3	-2		
21	203.0745	406.4454	203.0816	406.4588	-7	-2		
22	152.2888	406.4320	152.2914	406.4459	-3	-3		
23	101.4904	406.4140	101.4894	406.4267	1	-1		
24	50.7047	406.4016	50.7027	406.4124	2	1		
25	-0.0991	406.3938	-0.1042	406.4060	5	-1		
26	-0.0713	355.5906	-0.0761	355.6000	5	1		
27	-0.0648	304.8067	-0.0638	304.8157	-1	0		
28	-0.0390	254.0061	-0.0380	254.0111	-1	2		
29	-0.0281	203.2034	-0.0357	203.2092	8	0		
30	-0.0247	152.3951	-0.0302	152.4002	6	-1		
31	-0.0204	101.5917	-0.0232	101.5941	3	0		
32	-0.0088	50.7900	-0.0098	50.7957	1	-4		

Plate calibration values			Pos #5		UPSTREAM AREA		
Pt	Y(mm)	Z(mm)	Y(mm)	Z(mm)	Delta Y	DeltaZ	
					in microns		
1	0.0000	0.0000	-0.0003	0.0018	0	-2	BEFORE
2	50.8028	-0.0076	50.8021	-0.0108	1	3	
3	101.6012	-0.0092	101.5971	-0.0167	4	8	
4	152.4033	-0.0111	152.4011	-0.0224	2	11	
5	203.1899	-0.0058	203.1885	-0.0121	1	6	
6	253.9789	-0.0025	253.9803	-0.0096	-1	7	
7	304.7841	-0.0093	304.7872	-0.0184	-3	9	
8	355.5738	0.0034	355.5781	-0.0012	-4	5	
9	406.3747	0.0000	406.3800	0.0008	-5	-1	
10	406.3658	50.8077	406.3769	50.8097	-11	-2	
11	406.3500	101.5967	406.3652	101.5990	-15	-2	
12	406.3304	152.4029	406.3515	152.4071	-21	-4	
13	406.3155	203.2200	406.3386	203.2255	-23	-6	
14	406.3044	254.0239	406.3340	254.0294	-30	-6	
15	406.2888	304.8530	406.3236	304.8617	-35	-9	
16	406.2715	355.6567	406.3094	355.6645	-38	-8	
17	406.2475	406.4582	406.2916	406.4660	-44	-8	
18	355.4582	406.4515	355.5018	406.4536	-44	-2	
19	304.6602	406.4523	304.7045	406.4479	-44	4	
20	253.8724	406.4534	253.9169	406.4502	-44	3	
21	203.0745	406.4454	203.1165	406.4402	-42	5	
22	152.2888	406.4320	152.3303	406.4244	-41	8	
23	101.4904	406.4140	101.5327	406.4094	-42	5	
24	50.7047	406.4016	50.7487	406.3981	-44	3	
25	-0.0991	406.3938	-0.0540	406.3961	-45	-2	
26	-0.0713	355.5906	-0.0321	355.5939	-39	-3	
27	-0.0648	304.8067	-0.0300	304.8109	-35	-4	
28	-0.0390	254.0061	-0.0109	254.0090	-28	-3	
29	-0.0281	203.2034	-0.0096	203.2077	-19	-4	
30	-0.0247	152.3951	-0.0072	152.3986	-18	-3	
31	-0.0204	101.5917	-0.0108	101.5937	-10	-2	
32	-0.0088	50.7900	-0.0051	50.7985	-4	-8	
				Temperature and			
Plate calibration values			Pos #5		Squareness YZ corrected (0.000120 rad)		
Pt	Y(mm)	Z(mm)	Y(mm)	Z(mm)	Delta Y	DeltaZ	
					in microns		
1	0.0000	0.0000	-0.0003	0.0018	0	-2	AFTER
2	50.8028	-0.0076	50.8021	-0.0108	1	3	
3	101.6012	-0.0092	101.5971	-0.0167	4	8	
4	152.4033	-0.0111	152.4011	-0.0224	2	11	
5	203.1899	-0.0058	203.1885	-0.0121	1	6	
6	253.9789	-0.0025	253.9803	-0.0096	-1	7	
7	304.7841	-0.0093	304.7872	-0.0184	-3	9	

## MIT\_CHK5.XLS

8	355.5738	0.0034	355.5781	-0.0012	-4	5	
9	406.3747	0.0000	406.3800	0.0008	-5	-1	
10	406.3658	50.8077	406.3708	50.8097	-5	-2	
11	406.3500	101.5967	406.3530	101.5990	-3	-2	
12	406.3304	152.4029	406.3332	152.4071	-3	-4	
13	406.3155	203.2200	406.3142	203.2255	1	-6	
14	406.3044	254.0239	406.3035	254.0294	1	-6	
15	406.2888	304.8530	406.2870	304.8617	2	-9	
16	406.2715	355.6567	406.2667	355.6645	5	-8	
17	406.2475	406.4582	406.2428	406.4660	5	-8	
18	355.4582	406.4515	355.4530	406.4536	5	-2	
19	304.6602	406.4523	304.6557	406.4479	4	4	
20	253.8724	406.4534	253.8681	406.4502	4	3	
21	203.0745	406.4454	203.0677	406.4402	7	5	
22	152.2888	406.4320	152.2815	406.4244	7	8	
23	101.4904	406.4140	101.4839	406.4094	6	5	
24	50.7047	406.4016	50.6999	406.3981	5	3	
25	-0.0991	406.3938	-0.1028	406.3961	4	-2	
26	-0.0713	355.5906	-0.0748	355.5939	3	-3	
27	-0.0648	304.8067	-0.0666	304.8109	2	-4	
28	-0.0390	254.0061	-0.0414	254.0090	2	-3	
29	-0.0281	203.2034	-0.0340	203.2077	6	-4	
30	-0.0247	152.3951	-0.0255	152.3986	1	-3	
31	-0.0204	101.5917	-0.0230	101.5937	3	-2	
32	-0.0088	50.7900	-0.0112	50.7985	2	-8	

Plate calibration values			Pos #7		DOWNSTREAM AREA		
Pt	X(mm)	Y(mm)	X(mm)	Y(mm)	Delta X	DeltaY	
					in microns		
1	0.0000	0.0000	0.0006	0.0021	-1	-2	BEFORE
2	50.8028	-0.0076	50.8046	-0.0026	-2	-5	
3	101.6012	-0.0092	101.6091	-0.0018	-8	-7	
4	152.4033	-0.0111	152.4111	-0.0068	-8	-4	
5	203.1899	-0.0058	203.1943	-0.0009	-4	-5	
6	253.9789	-0.0025	253.9867	0.0000	-8	-3	
7	304.7841	-0.0093	304.7940	-0.0076	-10	-2	
8	355.5738	0.0034	355.5820	0.0035	-8	0	
9	406.3747	0.0000	406.3840	-0.0001	-9	0	
10	406.3658	50.8077	406.3728	50.8074	-7	0	
11	406.3500	101.5967	406.3515	101.5972	-1	-1	
12	406.3304	152.4029	406.3281	152.4034	2	-1	
13	406.3155	203.2200	406.3030	203.2221	12	-2	
14	406.3044	254.0239	406.2958	254.0268	9	-3	
15	406.2888	304.8530	406.2779	304.8599	11	-7	
16	406.2715	355.6567	406.2513	355.6638	20	-7	
17	406.2475	406.4582	406.2257	406.4660	22	-8	
18	355.4582	406.4515	355.4352	406.4629	23	-11	
19	304.6602	406.4523	304.6389	406.4633	21	-11	
20	253.8724	406.4534	253.8491	406.4654	23	-12	
21	203.0745	406.4454	203.0434	406.4589	31	-14	
22	152.2888	406.4320	152.2613	406.4477	28	-16	
23	101.4904	406.4140	101.4631	406.4299	27	-16	
24	50.7047	406.4016	50.6691	406.4147	36	-13	
25	-0.0991	406.3938	-0.1387	406.4065	40	-13	
26	-0.0713	355.5906	-0.1059	355.6026	35	-12	
27	-0.0648	304.8067	-0.0903	304.8187	26	-12	
28	-0.0390	254.0061	-0.0621	254.0132	23	-7	
29	-0.0281	203.2034	-0.0530	203.2108	25	-7	
30	-0.0247	152.3951	-0.0398	152.4016	15	-6	
31	-0.0204	101.5917	-0.0290	101.5965	9	-5	
32	-0.0088	50.7900	-0.0113	50.7998	3	-10	
				Temperature and			
Plate calibration values			Pos #7		Squareness XY corrected (-0.000087 rad)		
Pt	X(mm)	Y(mm)	X(mm)	Y(mm)	Delta X	DeltaY	
					in microns		
1	0.0000	0.0000	0.0006	0.0021	-1	-2	AFTER
2	50.8028	-0.0076	50.8046	-0.0026	-2	-5	
3	101.6012	-0.0092	101.6091	-0.0018	-8	-7	
4	152.4033	-0.0111	152.4111	-0.0068	-8	-4	
5	203.1899	-0.0058	203.1943	-0.0009	-4	-5	
6	253.9789	-0.0025	253.9867	0.0000	-8	-3	
7	304.7841	-0.0093	304.7940	-0.0076	-10	-2	



## MIT\_CHK7.XLS

8	355.5738	0.0034	355.5820	0.0035	-8	0		
9	406.3747	0.0000	406.3840	-0.0001	-9	0		
10	406.3658	50.8077	406.3762	50.8074	-10	2		
11	406.3500	101.5967	406.3583	101.5972	-8	3		
12	406.3304	152.4029	406.3383	152.4034	-8	4		
13	406.3155	203.2200	406.3166	203.2221	-1	4		
14	406.3044	254.0239	406.3128	254.0268	-8	5		
15	406.2888	304.8530	406.2983	304.8599	-10	2		
16	406.2715	355.6567	406.2751	355.6638	-4	4		
17	406.2475	406.4582	406.2529	406.4660	-5	4		
18	355.4582	406.4515	355.4624	406.4629	-4	1		
19	304.6692	406.4523	304.6661	406.4633	-6	1		
20	253.8724	406.4534	253.8763	406.4654	-4	0		
21	203.0745	406.4454	203.0706	406.4589	4	-1		
22	152.2888	406.4320	152.2885	406.4477	0	-4		
23	101.4904	406.4140	101.4903	406.4299	0	-4		
24	50.7047	406.4016	50.6963	406.4147	8	-1		
25	-0.0991	406.3938	-0.1115	406.4065	12	-1		
26	-0.0713	355.5906	-0.0821	355.6026	11	-1		
27	-0.0648	304.8067	-0.0699	304.8187	5	-3		
28	-0.0390	254.0061	-0.0451	254.0132	6	1		
29	-0.0281	203.2034	-0.0394	203.2108	11	-1		
30	-0.0247	152.3951	-0.0296	152.4016	5	-2		
31	-0.0204	101.5917	-0.0222	101.5965	2	-2		
32	-0.0088	50.7900	-0.0079	50.7998	-1	-8		

MITCHK11.XLS

Plate calibration values			Pos #11	DOWNSTREAM AREA			
Pt	Y(mm)	Z(mm)	Y(mm)	Z(mm)	Delta Y	DeltaZ	
					in microns		
1	0.0000	0.0000	0.0002	-0.0035	0	4	BEFORE
2	50.8028	-0.0076	50.8036	-0.0151	-1	8	
3	101.6012	-0.0092	101.5994	-0.0175	2	8	
4	152.4033	-0.0111	152.4032	-0.0247	0	14	
5	203.1899	-0.0058	203.1908	-0.0158	-1	10	
6	253.9789	-0.0025	253.9827	-0.0118	-4	9	
7	304.7841	-0.0093	304.7884	-0.0198	-4	11	
8	355.5738	0.0034	355.5793	-0.0029	-5	6	
9	406.3747	0.0000	406.3818	-0.0011	-7	1	
10	406.3658	50.8077	406.3770	50.8084	-11	-1	
11	406.3500	101.5967	406.3677	101.5968	-18	0	
12	406.3304	152.4029	406.3523	152.4048	-22	-2	
13	406.3155	203.2200	406.3399	203.2225	-24	-2	
14	406.3044	254.0239	406.3362	254.0269	-32	-3	
15	406.2888	304.8530	406.3250	304.8590	-36	-6	
16	406.2715	355.6567	406.3111	355.6629	-40	-6	
17	406.2475	406.4582	406.2940	406.4647	-46	-7	
18	355.4582	406.4515	355.5033	406.4520	-45	0	
19	304.6602	406.4523	304.7057	406.4462	-46	6	
20	253.8724	406.4534	253.9174	406.4479	-45	5	
21	203.0745	406.4454	203.1177	406.4379	-43	7	
22	152.2888	406.4320	152.3332	406.4208	-44	11	
23	101.4904	406.4140	101.5333	406.4049	-43	9	
24	50.7047	406.4016	50.7495	406.3940	-45	8	
25	-0.0991	406.3938	-0.0522	406.3932	-47	1	
26	-0.0713	355.5906	-0.0305	355.5894	-41	1	
27	-0.0648	304.8067	-0.0280	304.8061	-37	1	
28	-0.0390	254.0061	-0.0089	254.0043	-30	2	
29	-0.0281	203.2034	-0.0065	203.2033	-22	0	
30	-0.0247	152.3951	-0.0068	152.3944	-18	1	
31	-0.0204	101.5917	-0.0078	101.5924	-13	-1	
32	-0.0088	50.7900	-0.0032	50.7944	-6	-4	
				Temperature and			
Plate calibration values			Pos #5	Squareness YZ corrected (0.000121 rad)			
Pt	Y(mm)	Z(mm)	Y(mm)	Z(mm)	Delta Y	DeltaZ	
					in microns		
1	0.0000	0.0000	0.0002	-0.0035	0	4	AFTER
2	50.8028	-0.0076	50.8036	-0.0151	-1	8	
3	101.6012	-0.0092	101.5994	-0.0175	2	8	
4	152.4033	-0.0111	152.4032	-0.0247	0	14	
5	203.1899	-0.0058	203.1908	-0.0158	-1	10	
6	253.9789	-0.0025	253.9827	-0.0118	-4	9	
7	304.7841	-0.0093	304.7884	-0.0198	-4	11	

## MITCHK11.XLS

8	355.5738	0.0034	355.5793	-0.0029	-6	6		
9	406.3747	0.0000	406.3818	-0.0011	-7	1		
10	406.3658	50.8077	406.3709	50.8084	-5	-1		
11	406.3500	101.5967	406.3555	101.5968	-6	0		
12	406.3304	152.4029	406.3340	152.4048	-4	-2		
13	406.3155	203.2200	406.3155	203.2225	0	-2		
14	406.3044	254.0239	406.3057	254.0269	-1	-3		
15	406.2888	304.8530	406.2884	304.8590	0	-6		
16	406.2715	355.6567	406.2684	355.6629	3	-6		
17	406.2475	406.4582	406.2452	406.4647	2	-7		
18	355.4582	406.4515	355.4545	406.4520	4	0		
19	304.6602	406.4523	304.6569	406.4462	3	6		
20	253.8724	406.4534	253.8686	406.4479	4	5		
21	203.0745	406.4454	203.0689	406.4379	6	7		
22	152.2888	406.4320	152.2844	406.4208	4	11		
23	101.4904	406.4140	101.4845	406.4049	6	9		
24	50.7047	406.4016	50.7007	406.3940	4	8		
25	-0.0991	406.3938	-0.1010	406.3932	2	1		
26	-0.0713	355.5906	-0.0732	355.5894	2	1		
27	-0.0648	304.8067	-0.0646	304.8061	0	1		
28	-0.0390	254.0061	-0.0394	254.0043	0	2		
29	-0.0281	203.2034	-0.0309	203.2033	3	0		
30	-0.0247	152.3951	-0.0251	152.3944	0	1		
31	-0.0204	101.5917	-0.0200	101.5924	0	-1		
32	-0.0088	50.7900	-0.0093	50.7944	0	-4		

## MITCHK10.XLS

Plate calibration values			Pos #10		DOWNSTREAM AREA		
Pt	X(mm)	Z(mm)	X(mm)	Z(mm)	Delta X	Delta Z	
					in microns		
1	0.0000	0.0000	0.0004	-0.0038	0	4	BEFORE
2	50.8028	-0.0076	50.8044	-0.0080	-2	0	
3	101.6012	-0.0092	101.6052	-0.0073	-4	-2	
4	152.4033	-0.0111	152.4072	-0.0088	-4	-2	
5	203.1899	-0.0058	203.1934	-0.0022	-4	-4	
6	253.9789	-0.0025	253.9847	0.0020	-6	-5	
7	304.7841	-0.0093	304.7944	-0.0033	-10	-6	
8	355.5738	0.0034	355.5828	0.0108	-9	-7	
9	406.3747	0.0000	406.3855	0.0070	-11	-7	
10	406.3658	50.8077	406.3750	50.8153	-9	-8	
11	406.3500	101.5967	406.3576	101.6042	-8	-8	
12	406.3304	152.4029	406.3382	152.4105	-8	-8	
13	406.3155	203.2200	406.3224	203.2299	-7	-10	
14	406.3044	254.0239	406.3211	254.0342	-17	-10	
15	406.2888	304.8530	406.3070	304.8656	-18	-13	
16	406.2715	355.6567	406.2880	355.6695	-17	-13	
17	406.2475	406.4582	406.2674	406.4726	-20	-14	
18	355.4582	406.4515	355.4762	406.4650	-18	-13	
19	304.6602	406.4523	304.6798	406.4657	-20	-13	
20	253.8724	406.4534	253.8898	406.4657	-17	-12	
21	203.0745	406.4454	203.0862	406.4571	-12	-12	
22	152.2888	406.4320	152.3031	406.4439	-14	-12	
23	101.4904	406.4140	101.5039	406.4246	-14	-11	
24	50.7047	406.4016	50.7113	406.4097	-7	-8	
25	-0.0991	406.3938	-0.0925	406.4009	-7	-7	
26	-0.0713	355.5906	-0.0653	355.5970	-6	-6	
27	-0.0648	304.8067	-0.0579	304.8119	-7	-5	
28	-0.0390	254.0061	-0.0342	254.0075	-5	-1	
29	-0.0281	203.2034	-0.0341	203.2070	6	-4	
30	-0.0247	152.3951	-0.0290	152.3966	4	-1	
31	-0.0204	101.5917	-0.0256	101.5912	5	1	
32	-0.0088	50.7900	-0.0114	50.7944	3	-4	
				Temperature and			
Plate calibration values			Pos #10		Squareness XZ corrected (0.000049 rad)		
Pt	X(mm)	Z(mm)	X(mm)	Z(mm)	Delta X	Delta Z	
					in microns		
1	0.0000	0.0000	0.0004	-0.0038	0	4	AFTER
2	50.8028	-0.0076	50.8044	-0.0080	-2	0	
3	101.6012	-0.0092	101.6052	-0.0073	-4	-2	
4	152.4033	-0.0111	152.4072	-0.0088	-4	-2	
5	203.1899	-0.0058	203.1934	-0.0022	-4	-4	
6	253.9789	-0.0025	253.9847	0.0020	-6	-4	
7	304.7841	-0.0093	304.7944	-0.0033	-10	-6	

## MITCHK10.XLS

8	355.5738	0.0034	355.5828	0.0108	-9	-7		
9	406.3747	0.0000	406.3855	0.0070	-11	-7		
10	406.3658	50.8077	406.3732	50.8153	-7	-6		
11	406.3500	101.5967	406.3540	101.6042	-4	-5		
12	406.3304	152.4029	406.3329	152.4105	-2	-3		
13	406.3155	203.2200	406.3153	203.2299	0	-4		
14	406.3044	254.0239	406.3122	254.0342	-8	-3		
15	406.2888	304.8530	406.2963	304.8656	-8	-4		
16	406.2715	355.6567	406.2756	355.6695	-4	-3		
17	406.2475	406.4582	406.2532	406.4726	-6	-3		
18	355.4582	406.4515	355.4620	406.4650	-4	-2		
19	304.6502	406.4523	304.6656	406.4657	-5	-2		
20	253.8724	406.4534	253.8756	406.4657	-3	-1		
21	203.0745	406.4454	203.0720	406.4571	3	0		
22	152.2888	406.4320	152.2889	406.4439	0	-1		
23	101.4904	406.4140	101.4897	406.4246	1	1		
24	50.7047	406.4016	50.6971	406.4097	8	3		
25	-0.0991	406.3938	-0.1067	406.4009	8	4		
26	-0.0713	355.5906	-0.0777	355.5970	6	4		
27	-0.0648	304.8067	-0.0686	304.8119	4	3		
28	-0.0390	254.0061	-0.0431	254.0075	4	6		
29	-0.0281	203.2034	-0.0412	203.2070	13	2		
30	-0.0247	152.3951	-0.0343	152.3966	10	3		
31	-0.0204	101.5917	-0.0292	101.5912	9	3		
32	-0.0088	50.7900	-0.0132	50.7944	4	-3		