Development of a mover having one nanometer precision and 4mm moving range

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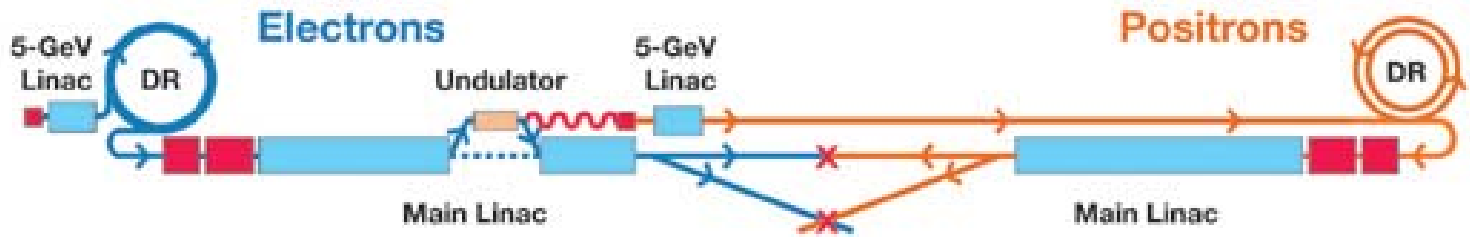
ILC (International Linear Collider)

- Next generation large linear accelerator
- The beam size at the interaction region is several nm



Motivation for the mover

The beam size is several nm

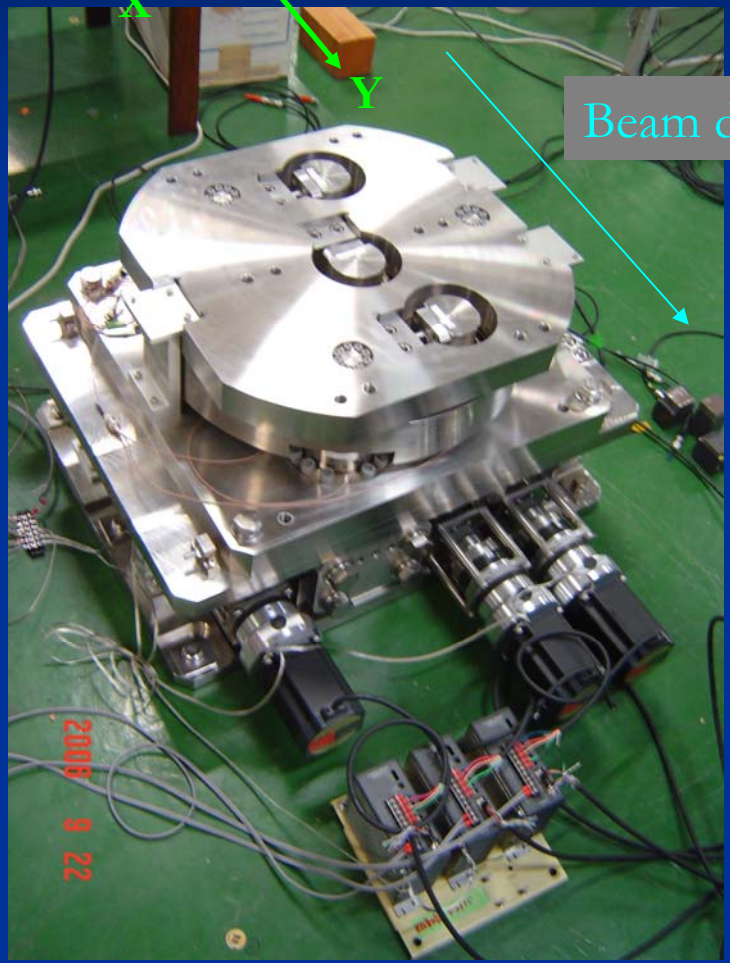
require

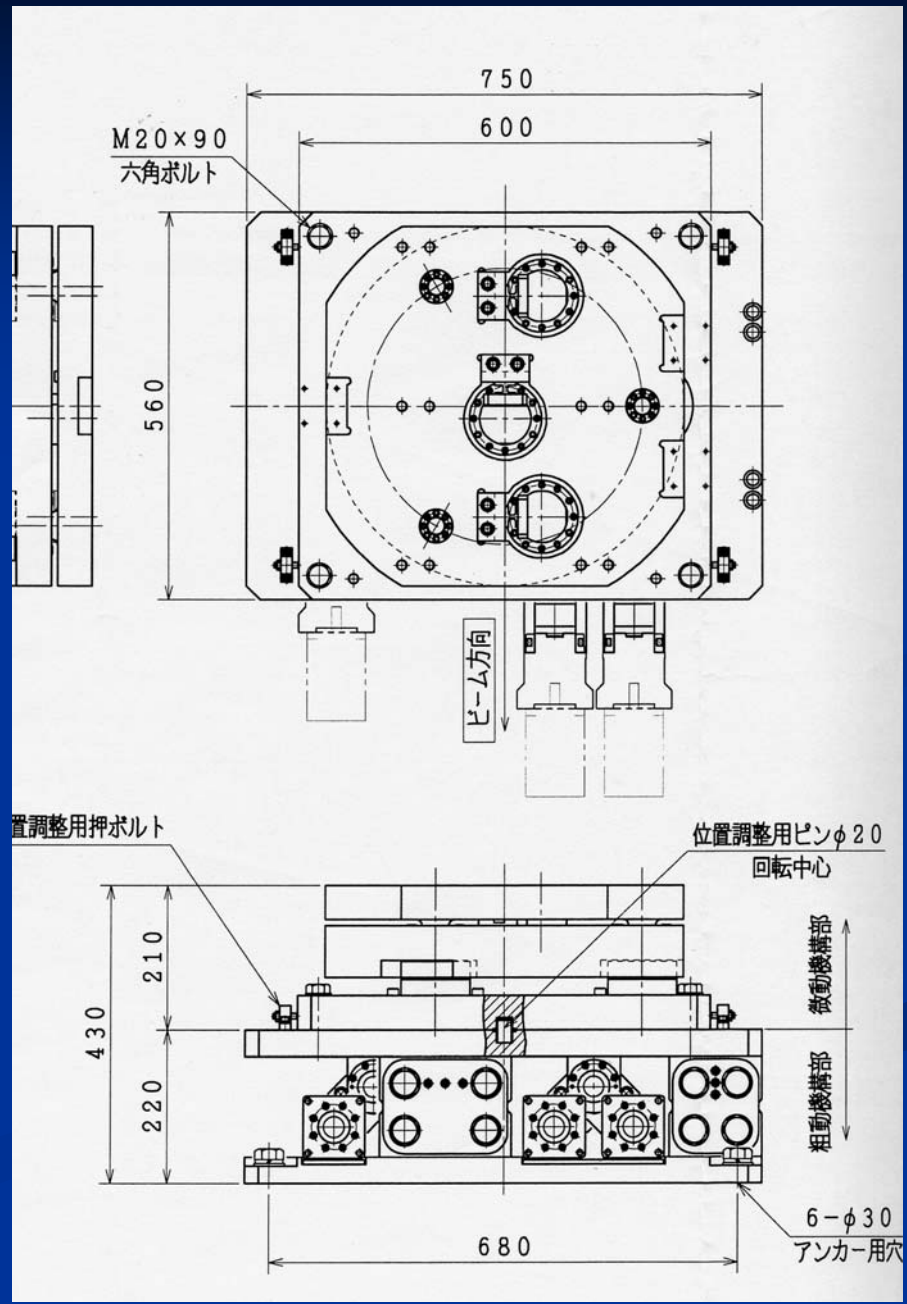
1nm precision alignment of components

Purpose of the mover

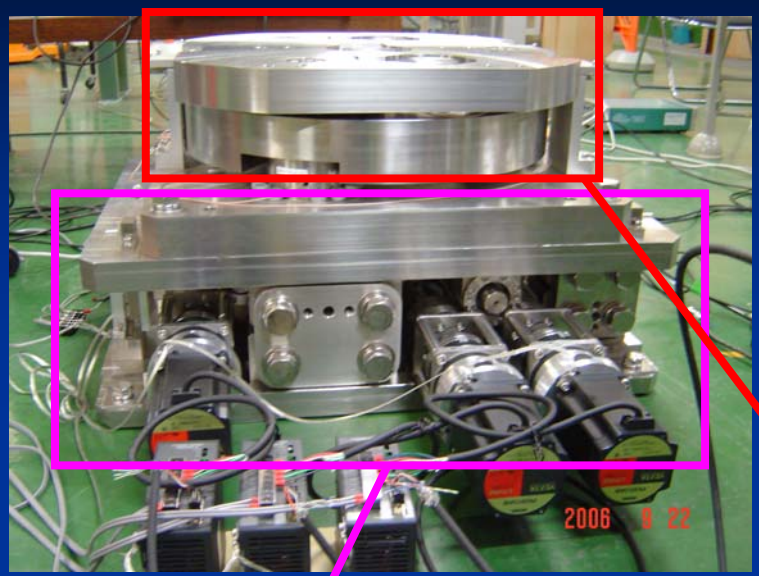
- Fine tuning for the position of ILC components (1nm precision)
- Wide range adjustment (4.5mm)

Specification





Specification



- Mass: about 350kg
- Material: SUS303
- The load limit: about 700kg

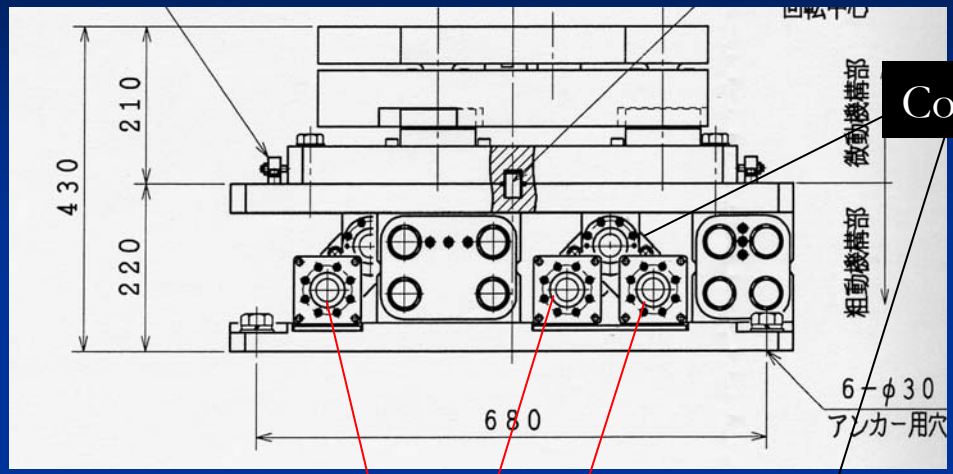
Cam mover

This mover is for wide range adjustment
3 motors
X, V and θy directions
Moving range: 4.5mm
Moving precision: 0.1μm

Piezoelectric mover

This mover is for fine tuning
6 piezoelectric transducers
X, Y, V and θx, θy, θv directions
Moving range: 0.4μm
Moving precision: 1nm

Cam mover



Connecting arm

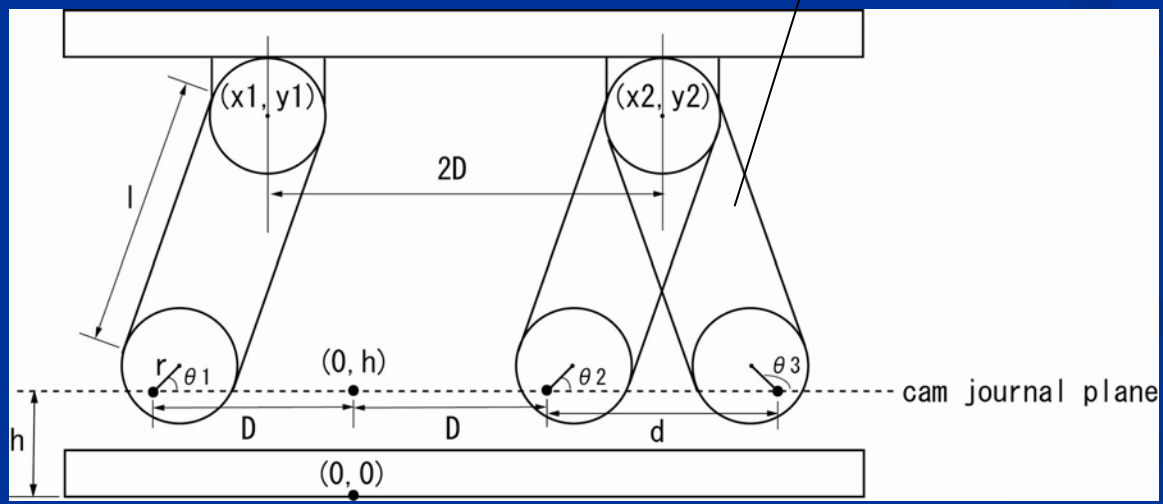
Center
of the thick shaft

motor

Rotation axis

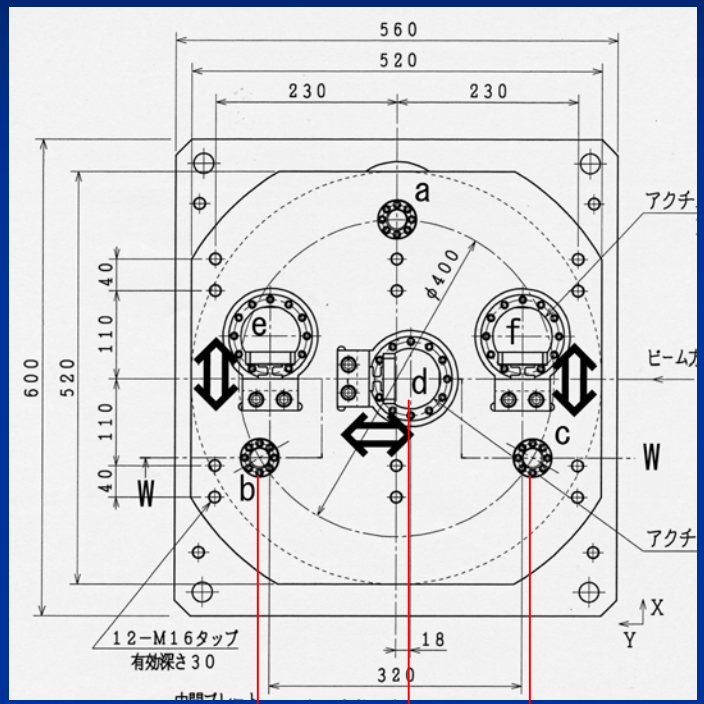
V
X

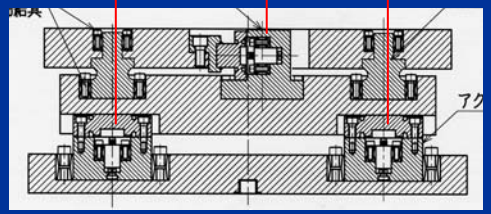
3 motors
Shafts with offsets



Top table moves
in X, V and θy directions

Piezoelectric mover

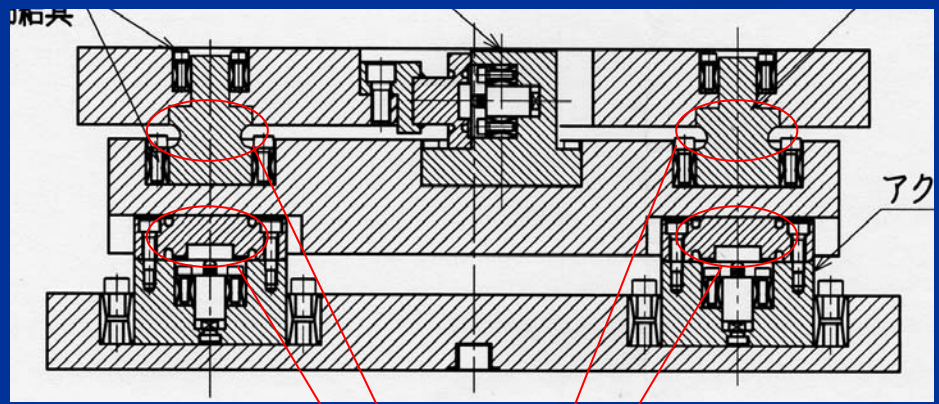




The cross section along the line W

3 piezoelectric transducers for vertical motion
3 piezoelectric transducers for horizontal motion

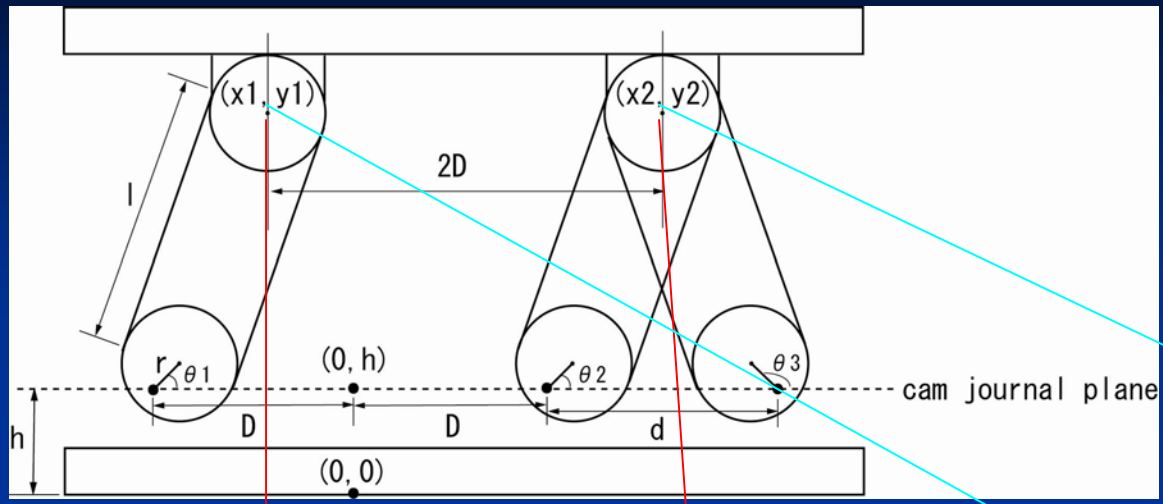
The table moves
X, Y, V and θx, θy, θv directions



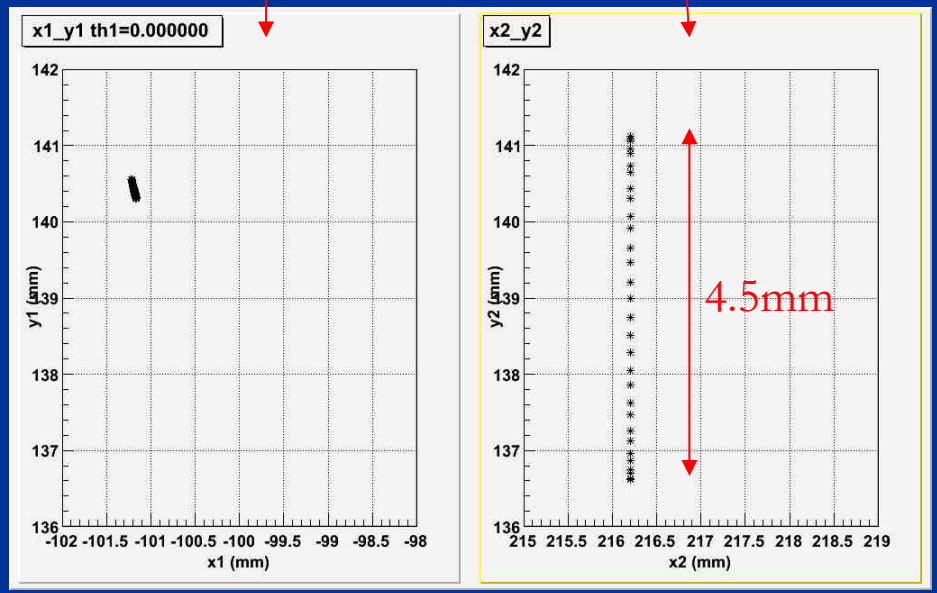
springs

Cam mover

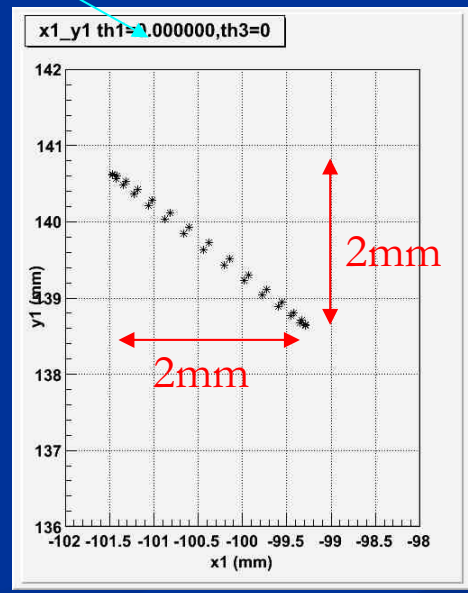
Calculation of the cam mover motion

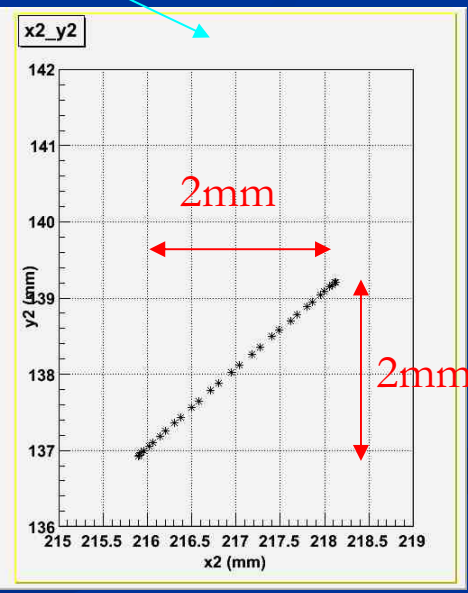


$$(x_1-r\cdot\cos\theta_1+D)^2+(y_1-r\cdot\sin\theta_1-h)^2=l^2$$
$$(x_2-r\cdot\cos\theta_2-D)^2+(y_2-r\cdot\sin\theta_2-h)^2=l^2$$
$$(x_2-r\cdot\cos\theta_3-D-d)^2+(y_2-r\cdot\sin\theta_3-h)^2=l^2$$
$$(x_2-x_1)^2+(y_2-y_1)^2=4\cdot D^2$$



θ1=0, θ2=π−θ3
θ2 and θ3 are rotated.



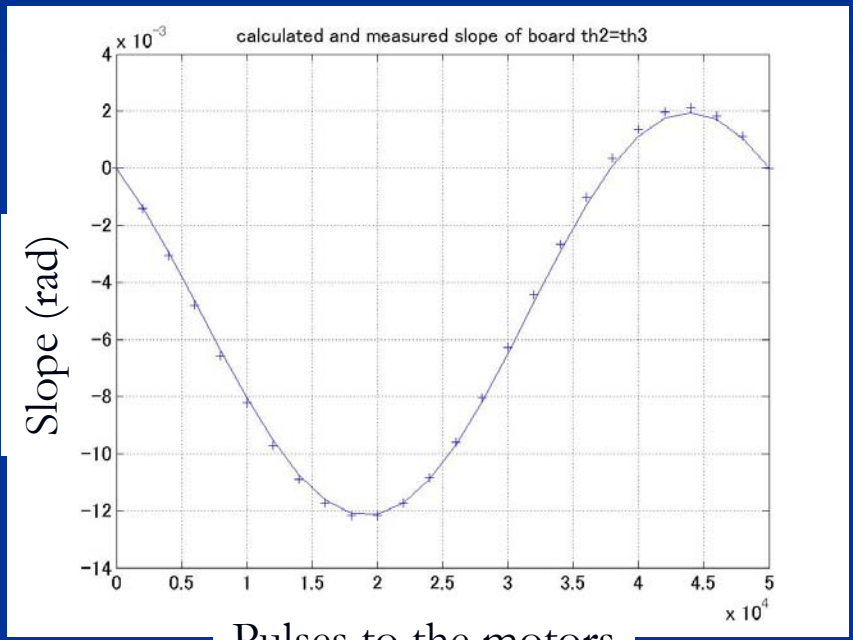


θ1=θ3=0
θ2 is rotated.

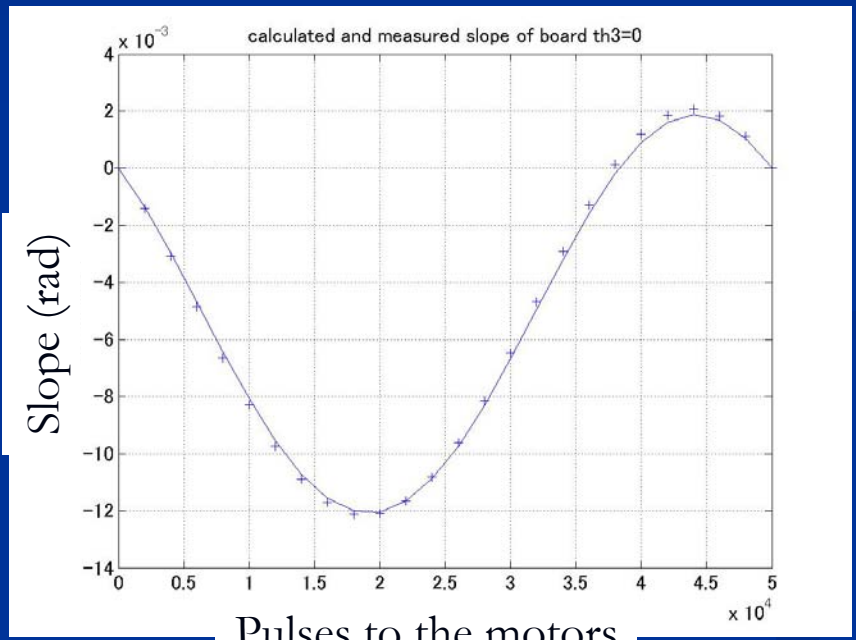
Comparison between calculation and measurement

Slope of the table is compared

Solid line: calculation result
"+"marks: measurement



θ1=0, θ2=π–θ3
θ2 and θ3 are rotated.



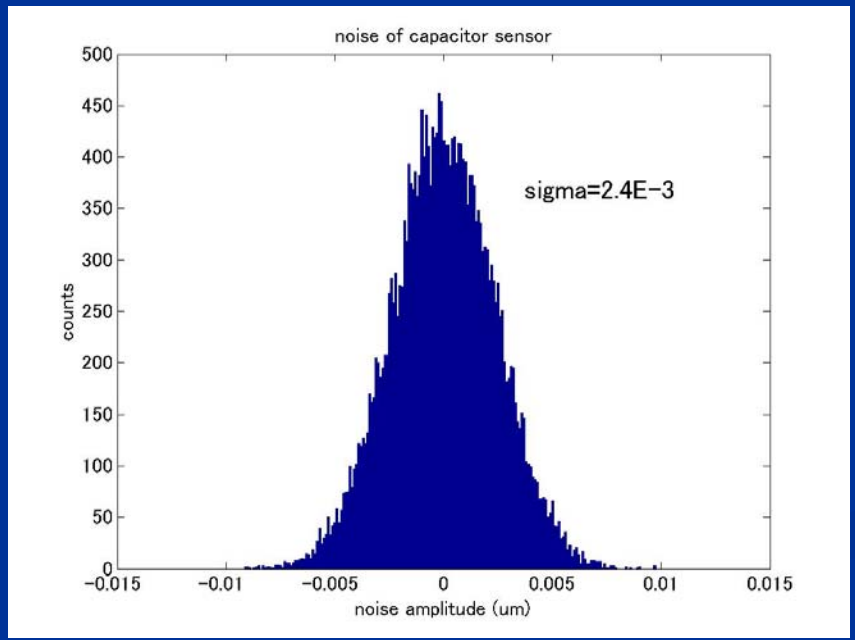
θ1=θ3=0
θ2 is rotated.

Piezoelectric mover

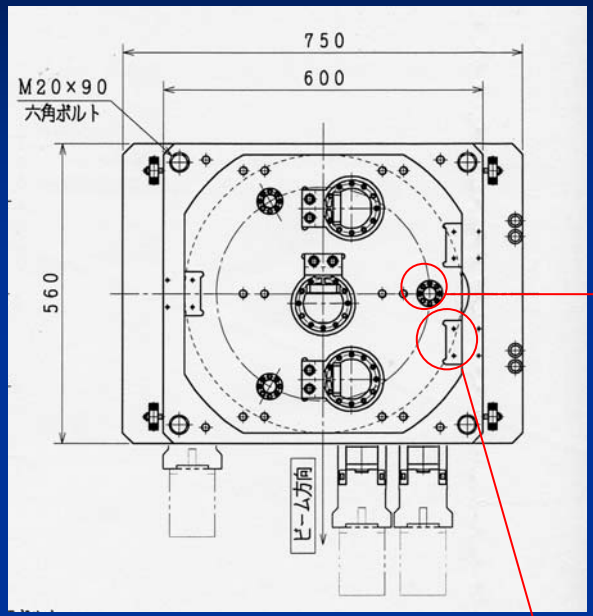
Noise of the capacitive sensor

A capacitive sensor is used to examine the property of the piezoelectric transducers

- Sampling rate is 2.54kHz
- For 10 seconds
- Standard deviation is 2.4nm

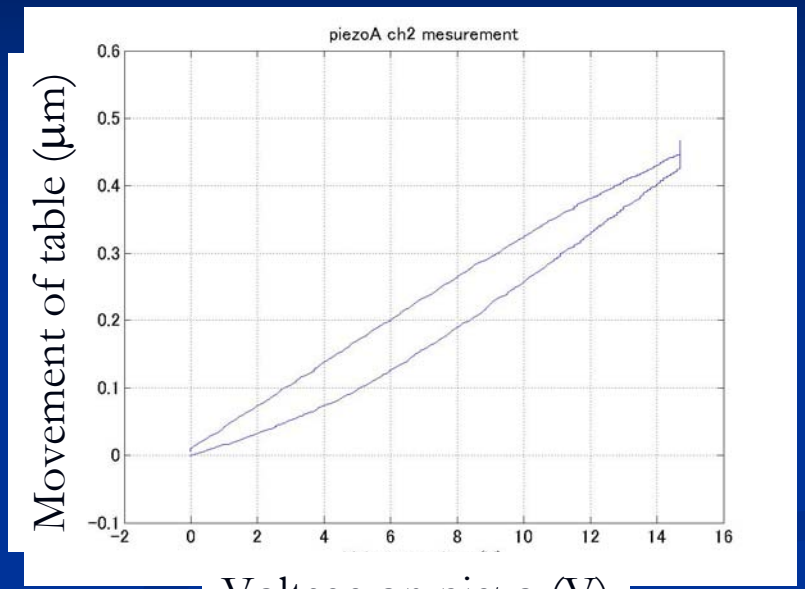


Piezo motion



Piezoelectric transducer

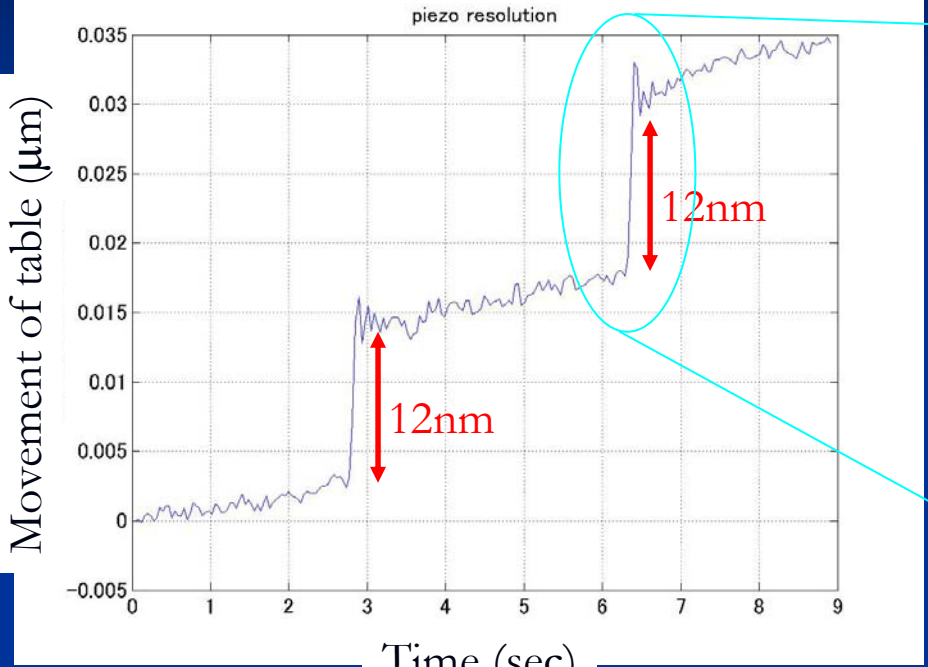
Capacitance type displacement sensor

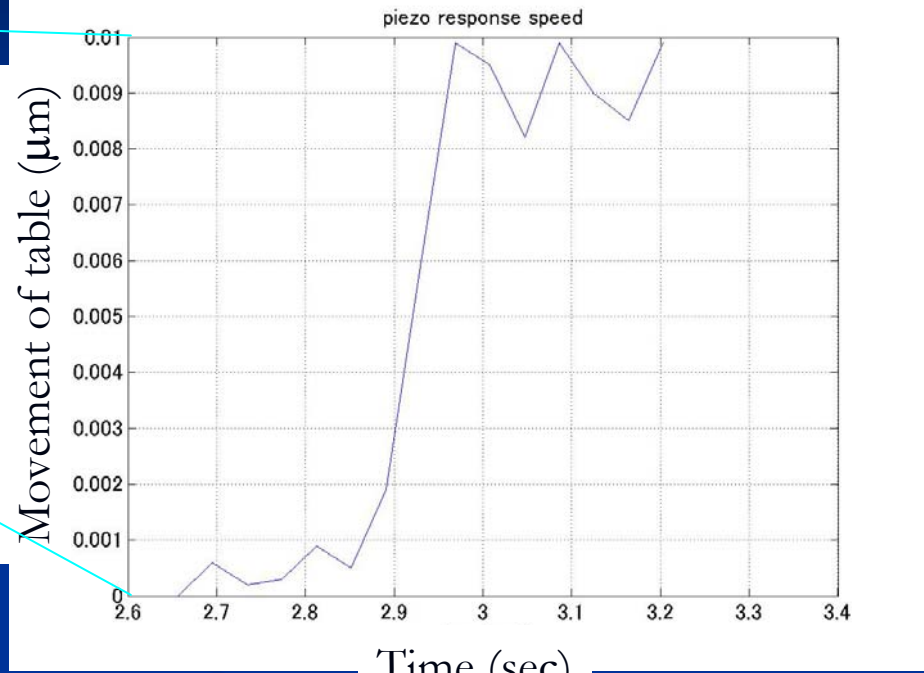


Moving range is about 0.4μm

A piezoelectric transducer has a hysteresis

Piezo resolution and response speed





Resolution 1 or 2nm can be expected

Response speed of the piezoelectric transducer is 56μm/sec

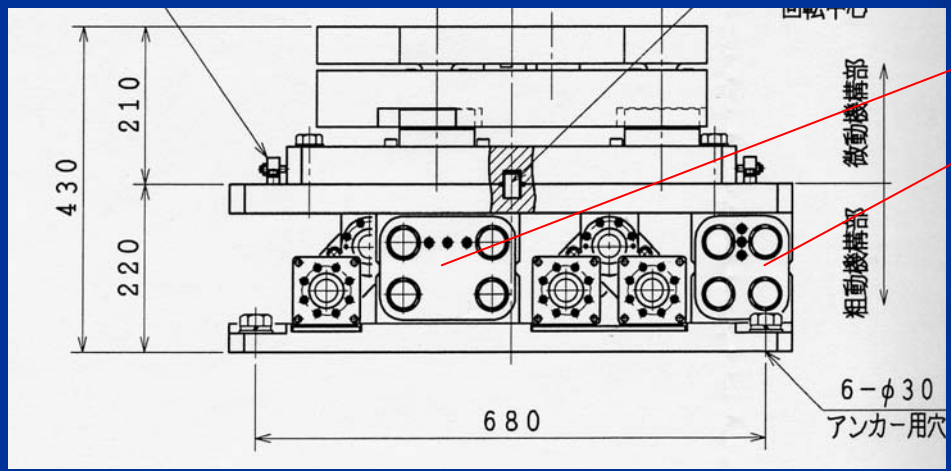
Vibration cancellation and natural vibration of the mover

Up to 30Hz vibration cancellation system will be developed

near

Natural vibration of the mover is 45Hz

Stoppers are installed to shift the natural vibration frequency

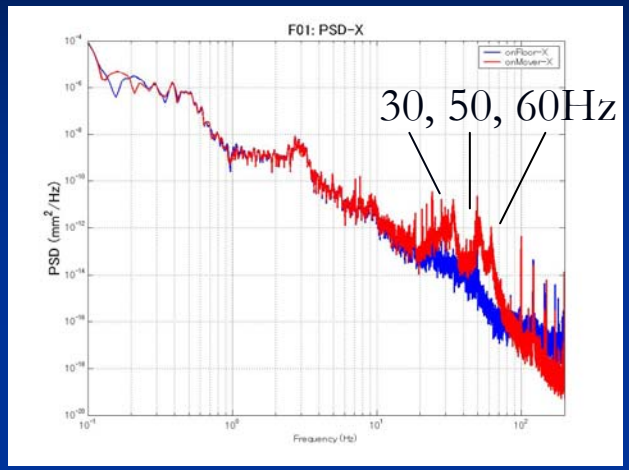


stoppers

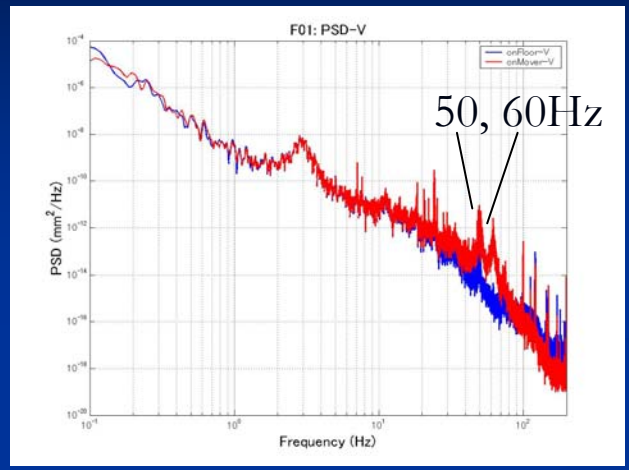
Vibration of the table (PSD)

Red: on the table
Blue: on the floor

Without stoppers

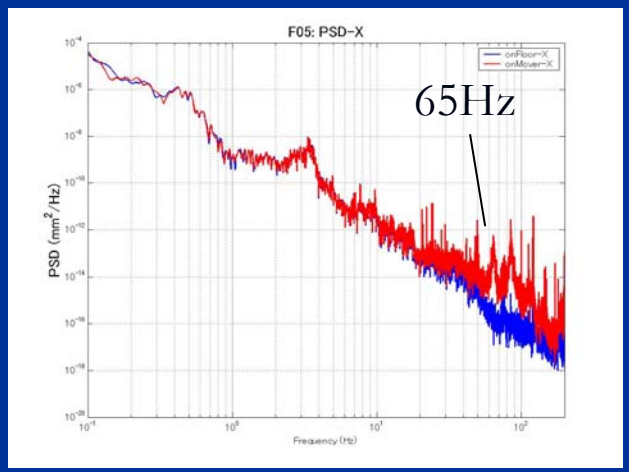


X direction

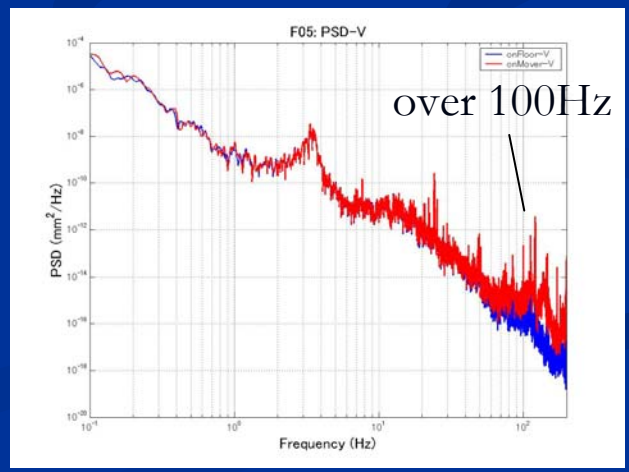


Vertical direction

With stoppers



X direction



Vertical direction

Summary

- Moving range 4.5mm + 0.4μm
- 12nm step was clearly observed

  →1 or 2nm resolution can be expected
- Response speed of the piezo is 56μm/sec
- Natural frequency of the mover is 65Hz or higher with stoppers

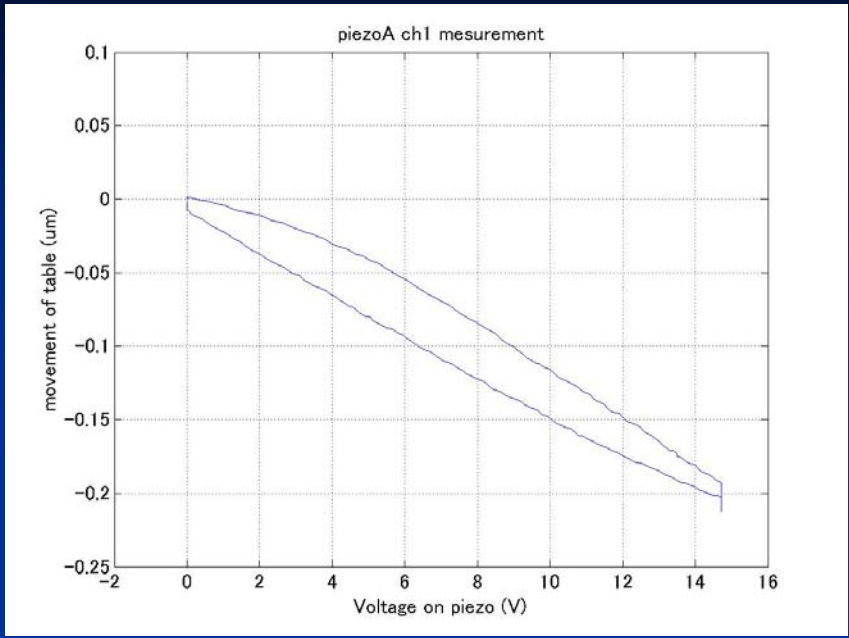
Future prospect

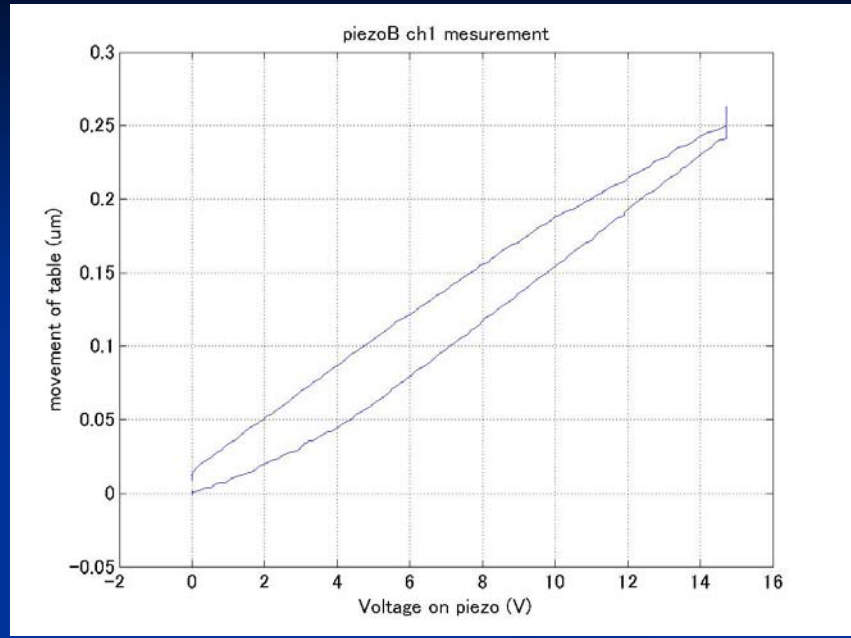
1. Measure again with more sensitive and stable sensors

The response speed of the piezoelectric transducer is high (56μm/sec)

2. Develop the vibration cancellation system
   up to about 30Hz (In the region>30Hz, amplitude<1nm)
   feedback or feedforward
   Michelson-Morley or Fabry-Perot laser interferometer

The end of the slides


piezoA ch1 mesurement
movement of table (um)
Voltage on piezo (V)
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−2
0
2
4
6
8
10
12
14
16


piezoB ch1 mesurement
movement of table (um)
Voltage on piezo (V)
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05
−2
0
2
4
6
8
10
12
14
16

- Two stage mover
  - Rough mover stage --> Cam movers
  - Precision mover stage --> Piezo movers

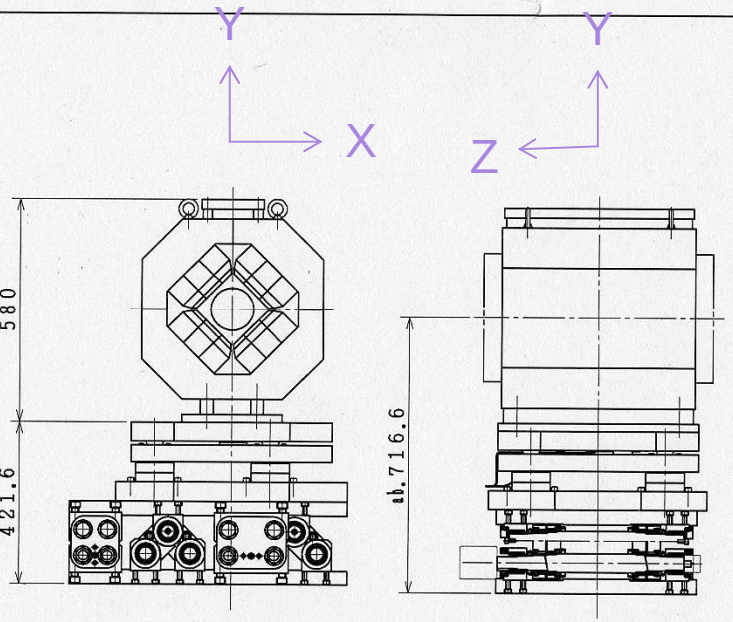
Specification

	Range	Resolution	Speed
Rough movers	±1.5 mm	0.1 μm	> 0.1 mm/sec
Precision movers	±0.2 μm	1 nm	> 0.5 μm/sec

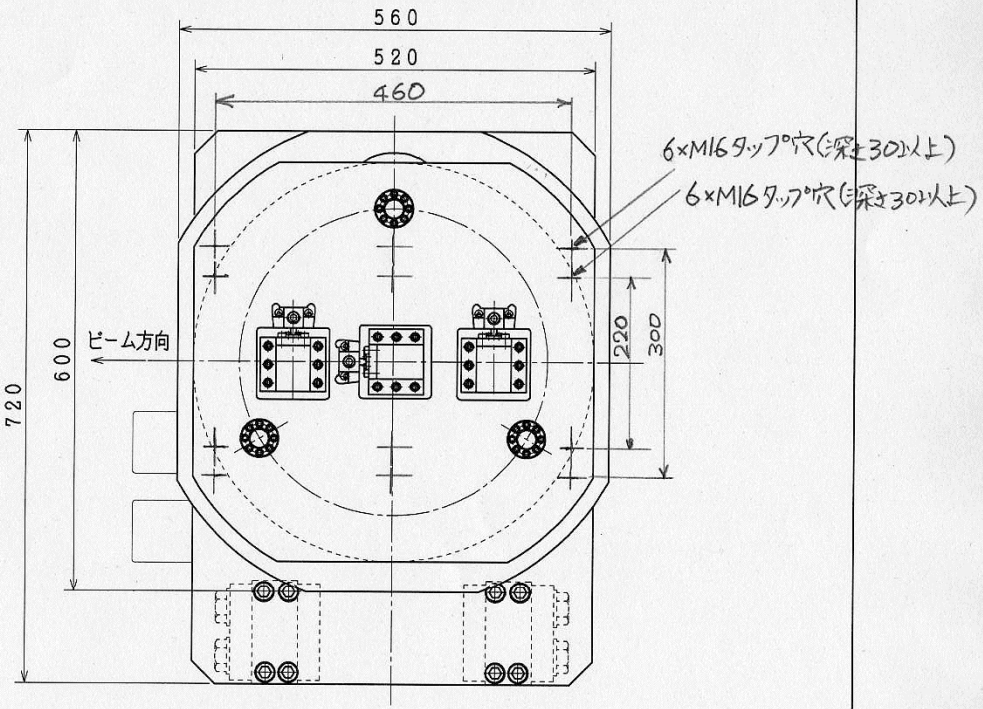
Need 5 directions (X, Y, Θ_X, Θ_Y, Θ_Z)

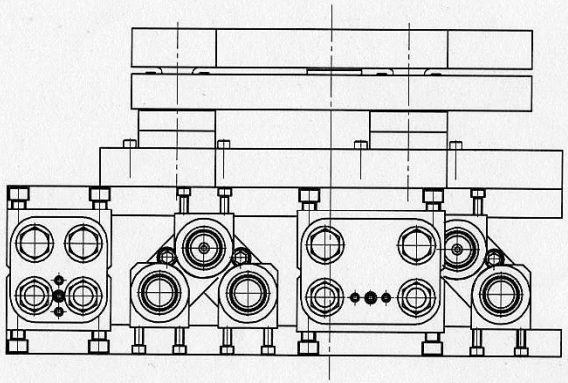
Max. weight of load is 2 tons

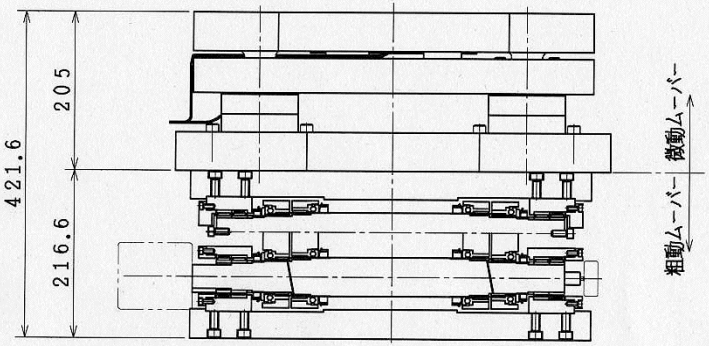
Size of table (to install QD0) 600 ×~ ×~ H



マグネット搭載図　S：1/12







No.	日付 DATE	内容 CONTENTS	変更 MOD	承認 APP
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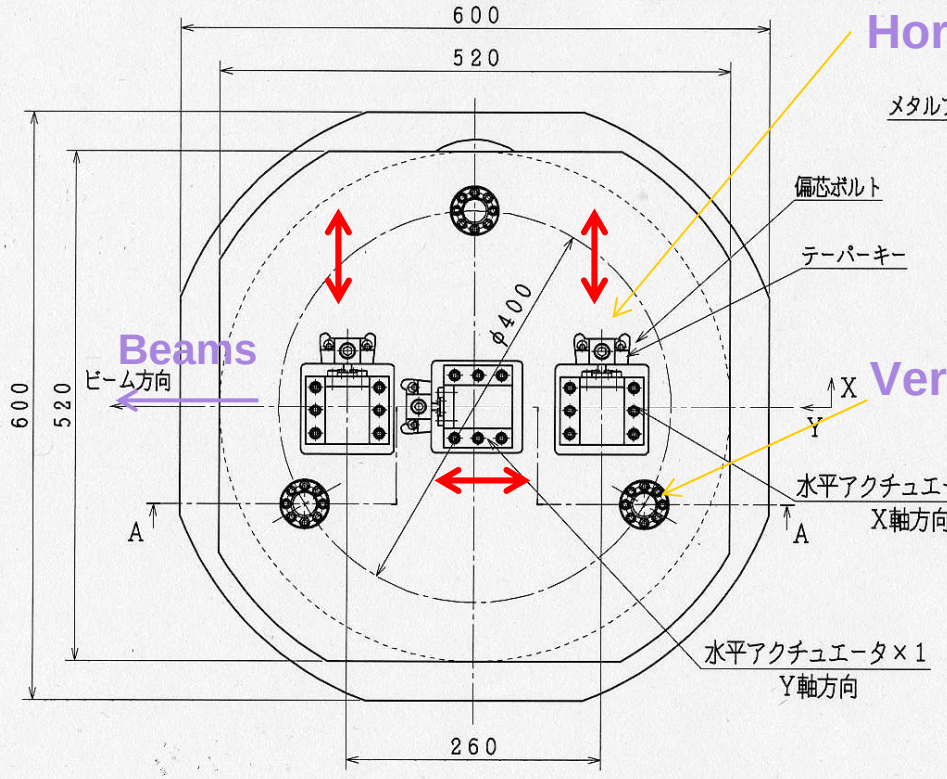
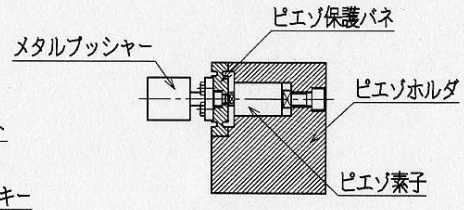
	・・			
	・・			

製図 DWN	加藤	日付 DATE 05・12・26	次世代加速器用超精密ムーバー	御納入先 Client	東京大学　殿
検図 CKD	潘	日付 DATE 05・12・26			
承認 APP	安田	日付 DATE 05・12・26	尺度 Scale. 1/5	NO. TDC-S090-014	E2 特許機器株式会社



Horizontal piezo actuator

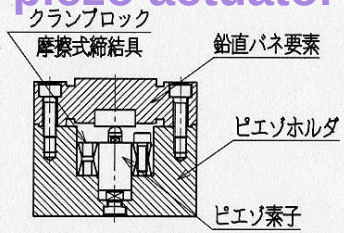


水平アクチュエータ断面図　S：1/3

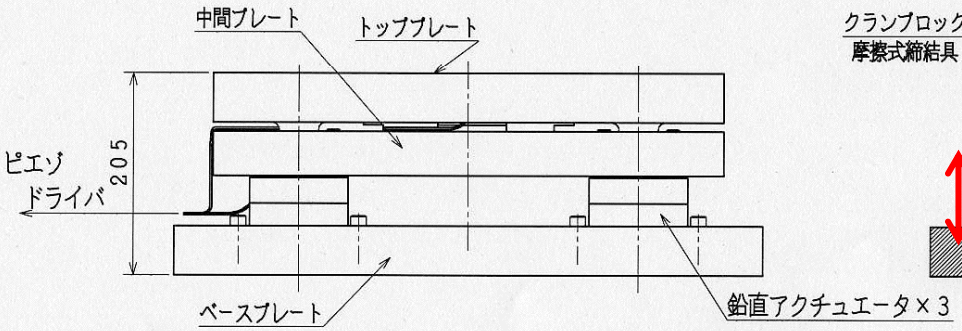
精密ムーバー　仕様

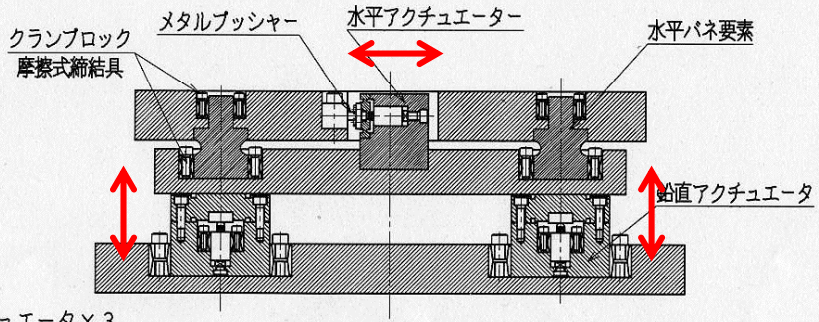
装置質量	約310 kg
装置材質	SUS303
搭載対象物	ATF2最終収束電磁石
搭載質量	約700 kg
調整機構	ピエゾアクチュエーター
位置検出センサー	取付部のみ

Vertical piezo actuator



鉛直アクチュエータ断面図　S：1/3



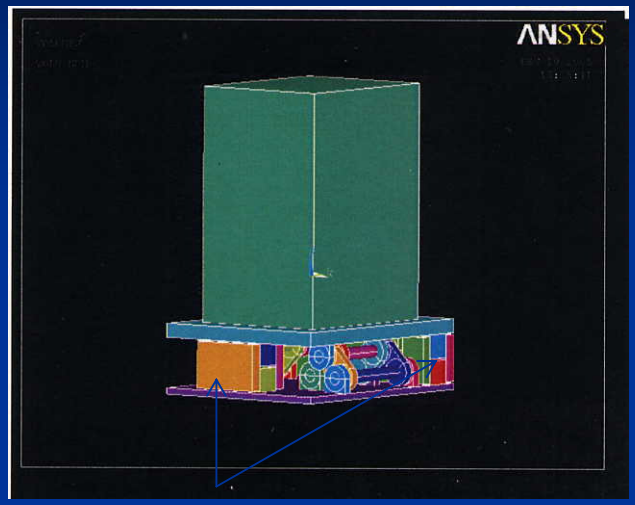


A－A断面図　S：1/5

No.	DATE 付	内容 CONTENTS	MOD 変更	APP 承認

製図 DWN	加藤	日付 DATE	05・12・26	次世代加速器用超精密ムーバー	御納入先 Client　東京大学　殿
検図 CKD	潘	日付 DATE	05・12・26	微動機構部	
承認 APP	安田	日付 DATE	05・12・26	尺度 Scale. 1/5　NO. TDC-S090-013	E2 特許機器株式会社

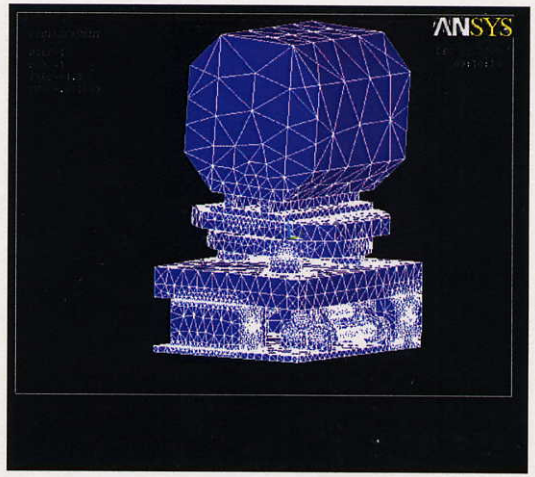
According to ANSYS calculation, rough mover stage is weak!
--> Stopper is installed



Stoppers

	w/o stoppers	With stoppers
Primary mode	45.1 Hz	187.6 Hz
Secondary mode	65.5	304.5
Third	148.6	635.5

Total system -->



第1次	84.500Hz
第2次	120.27Hz
第3次	248.69Hz
第4次	302.45Hz
第5次	412.62Hz