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Non-contact Thickness Measuring Device for Coating Process in Battery Manufacturing

CIML 安脉时代
CONTEMPORARY INTELLIGENT MANUFACTURING

Sponsor: Guangrong XIA, CIML

Instructor: Prof. Jigang WU

VE/VM450 Group 4

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Team Members

Yuenong Ling - Mechanical Analysis

ME + Engineering Physics

Jiajin Wu - Mechanical Design

ME

Zhiyang Chen - Software Development

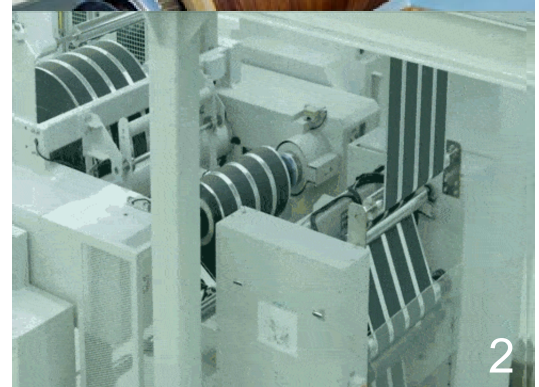
ECE + Computer Science

Zefang Li (Leader) - Logistics, Fabrication

ME

Background

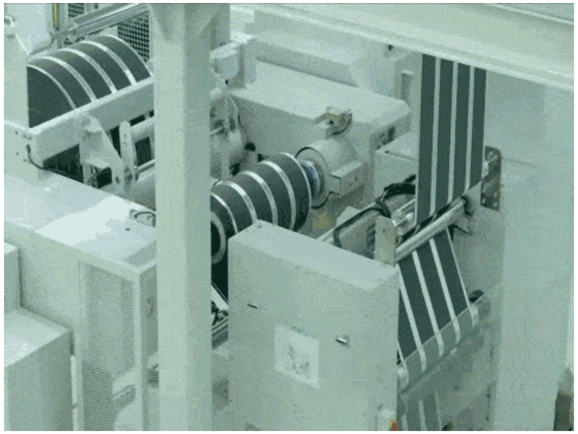
- Coating is omnipresent in our daily life
- Manufacturing of electrode sheet for Li-battery
- Potential damage of battery failure
- Need a reliable quality control process!



1. https://www.hotmelt.com/blogs/blog/complete-run-down-roll-coaters
2. https://m.sohu.com/a/420613358_607810/?pvid=000115_3w_a
3. https://abcnews.go.com/Technology/tesla-model-catch-fire/story?id=20462128

Needs

Real-time, continuous thickness measurement of electrode sheets (~155μm).



Requirements:

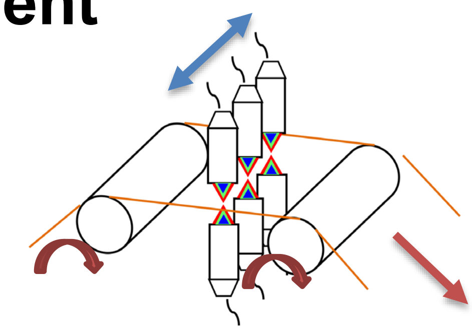
1. Low cost: < 100,000 RMB
2. Small-sized: less than 1.5 m × 1 m × 2 m
3. High precision: ± 0.5 μm
4. Good stability: pass measurement system assessment (MSA)

1. https://m.sohu.com/a/420613358_607810/?pvid=000115_3w_a

Solution

Measuring principle: Confocal Displacement

- Optical, compare the wavelength of the reflected light
- Sensors on both sides of electrode



Sensor diagram [1].

Hardware design: Stationary Sensor

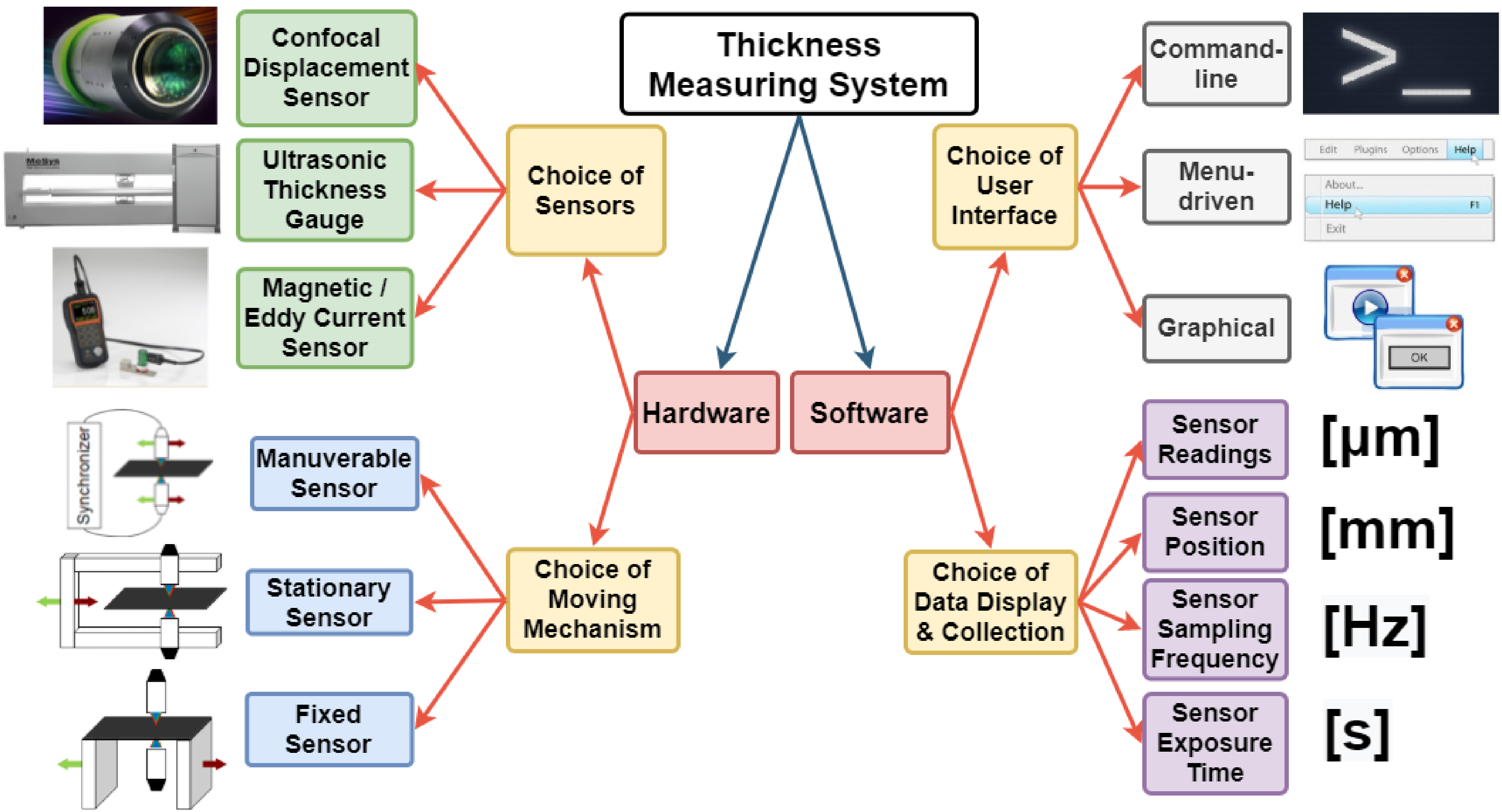
- Sensors installed on a maneuverable, rigid frame

Software design: Graphical User Interface

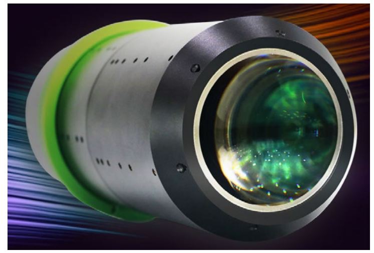
- Acquire, filter & visualize measurement data

1. http://www.lighte-tech.com/upload/file/contents/2020/06/5edb671526154.pdf

Concept Generation

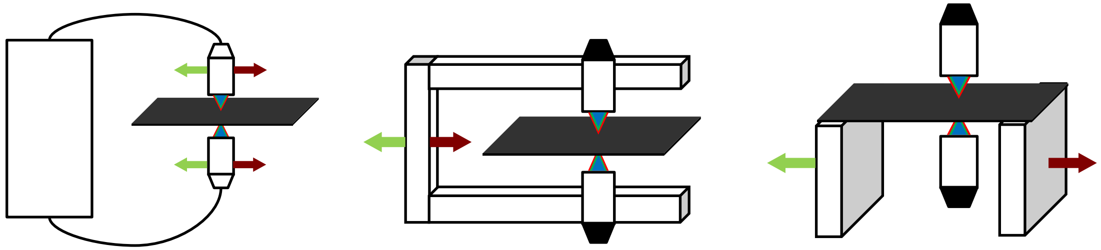


Concept Selection-Sensor



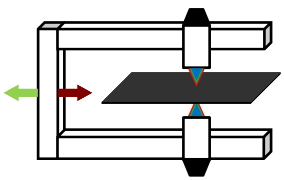
Working Principle		Confocal Light		Ultrasonic		Magnetic	
Criteria	Weight	Score	Rating	Score	Rating	Score	Rating
Range	0.10	3	0.30	5	0.50	5	0.50
Resolution	0.20	5	1.00	4	0.80	2	0.40
Linearity	0.20	4	0.80	4	0.80	2	0.80
Cost	0.20	3	0.60	1	0.20	5	1.00
Non-contact	0.20	5	1.00	5	1.00	1	0.20
Frequency	0.10	4	0.40	3	0.40	1	0.40
Total		4.10 ✔		3.70		3.30	

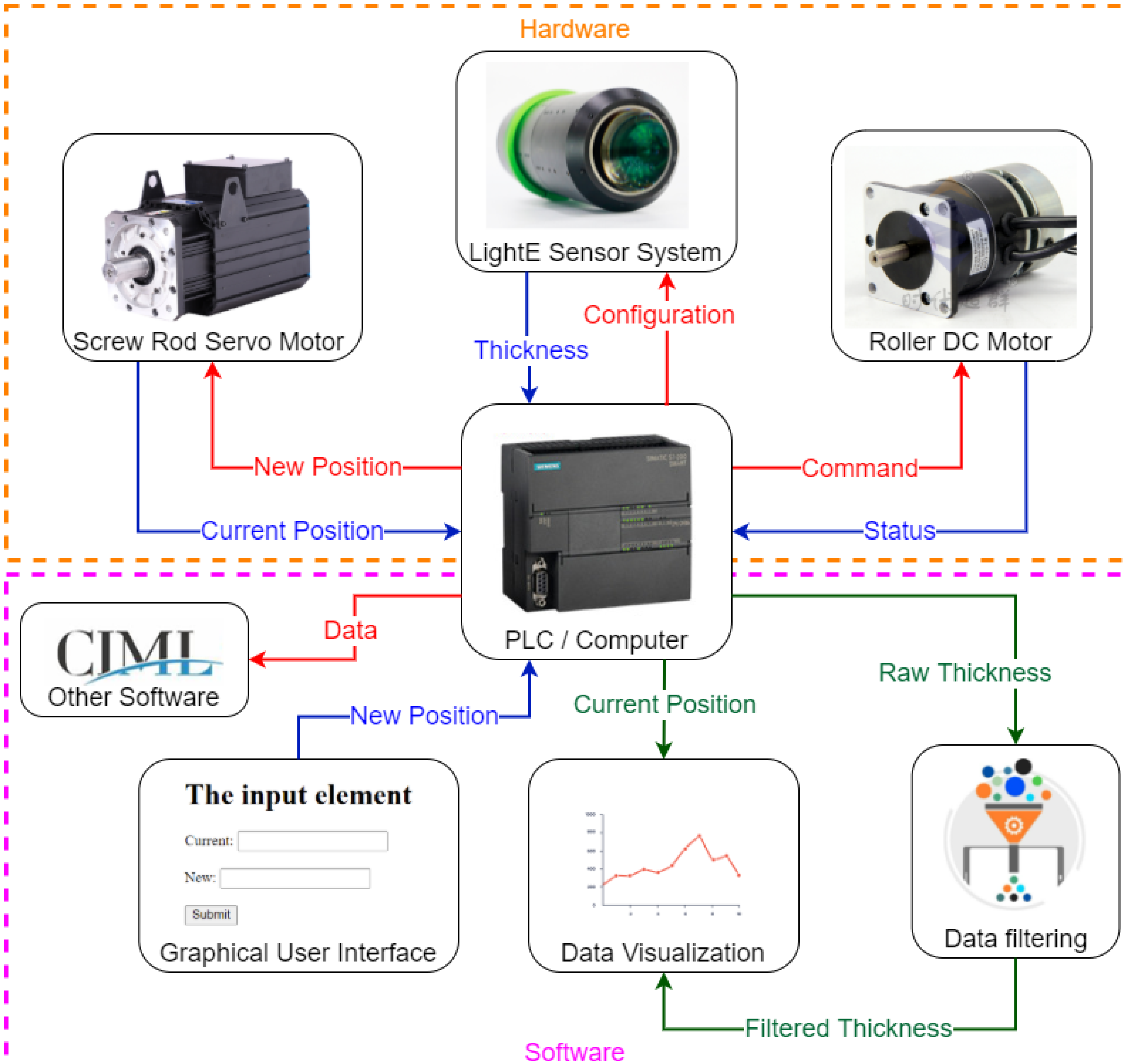
Concept Selection-Mov Mech

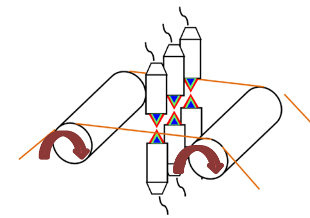


Type		Maneuverable		Stationary		Fixed	
Criteria	Weight	Score	Rating	Score	Rating	Score	Rating
Stability	0.25	2	0.50	3	0.75	4	1.00
Accuracy	0.12	3	0.36	3	0.36	3	0.36
Ease	0.10	1	0.10	3	0.30	4	0.40
Cost	0.25	2	0.50	3	0.75	2	0.50
Reliability	0.08	1	0.08	4	0.32	2	0.16
Size	0.20	3	0.60	4	0.80	1	0.20
Total		2.06		3.28 ✔		2.62	

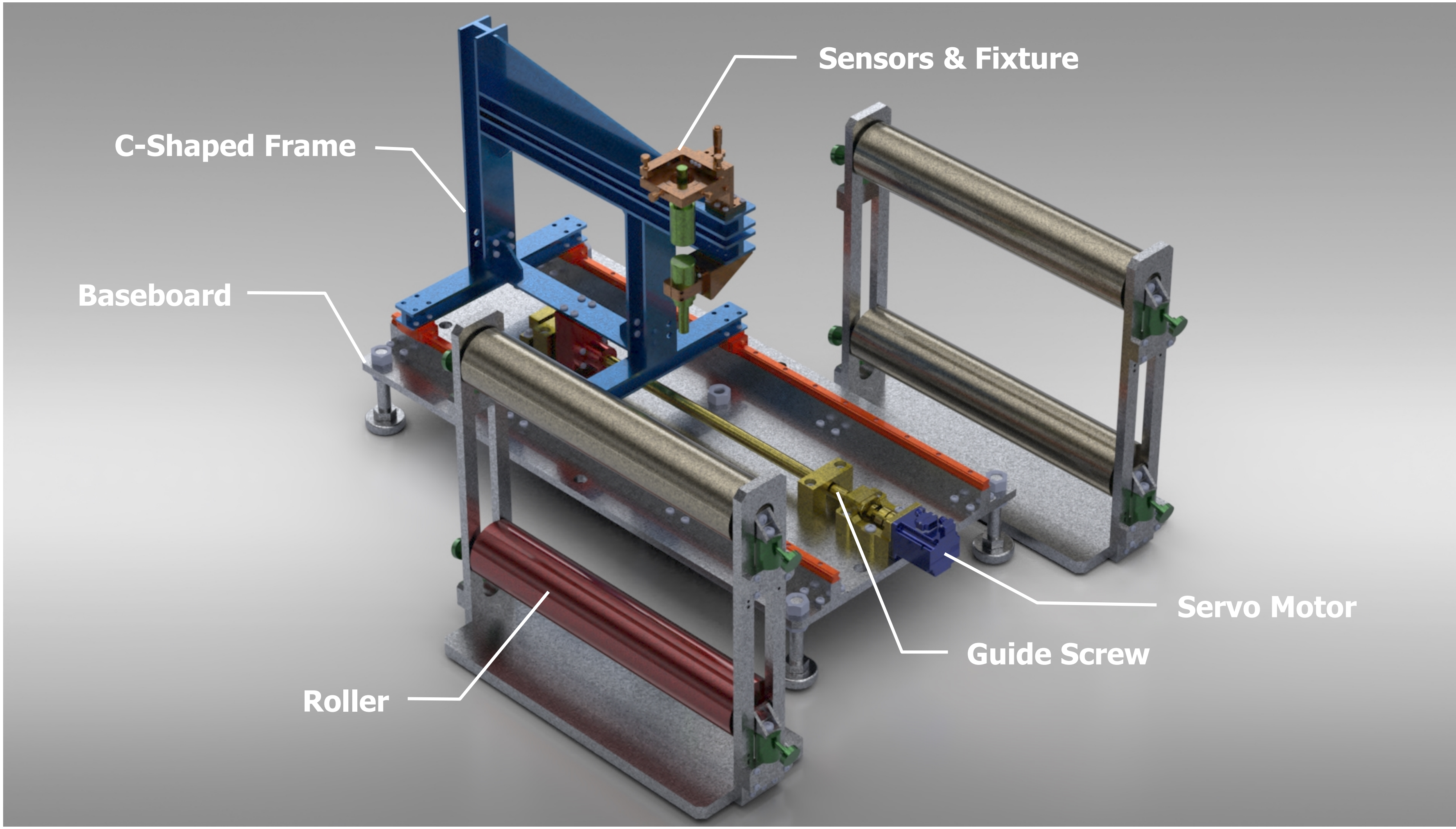
Final Design Concept



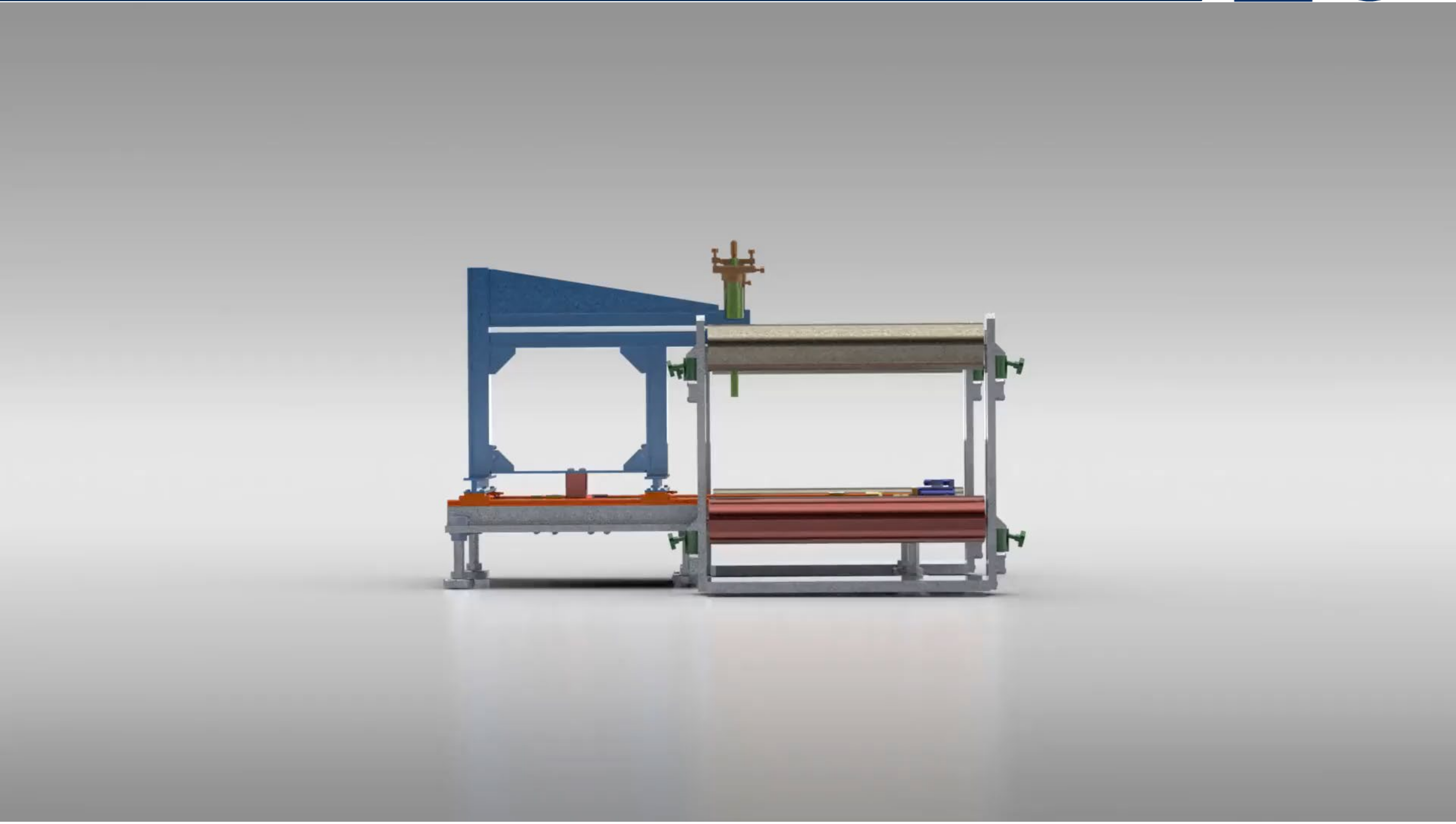




Final Design (Rendering)

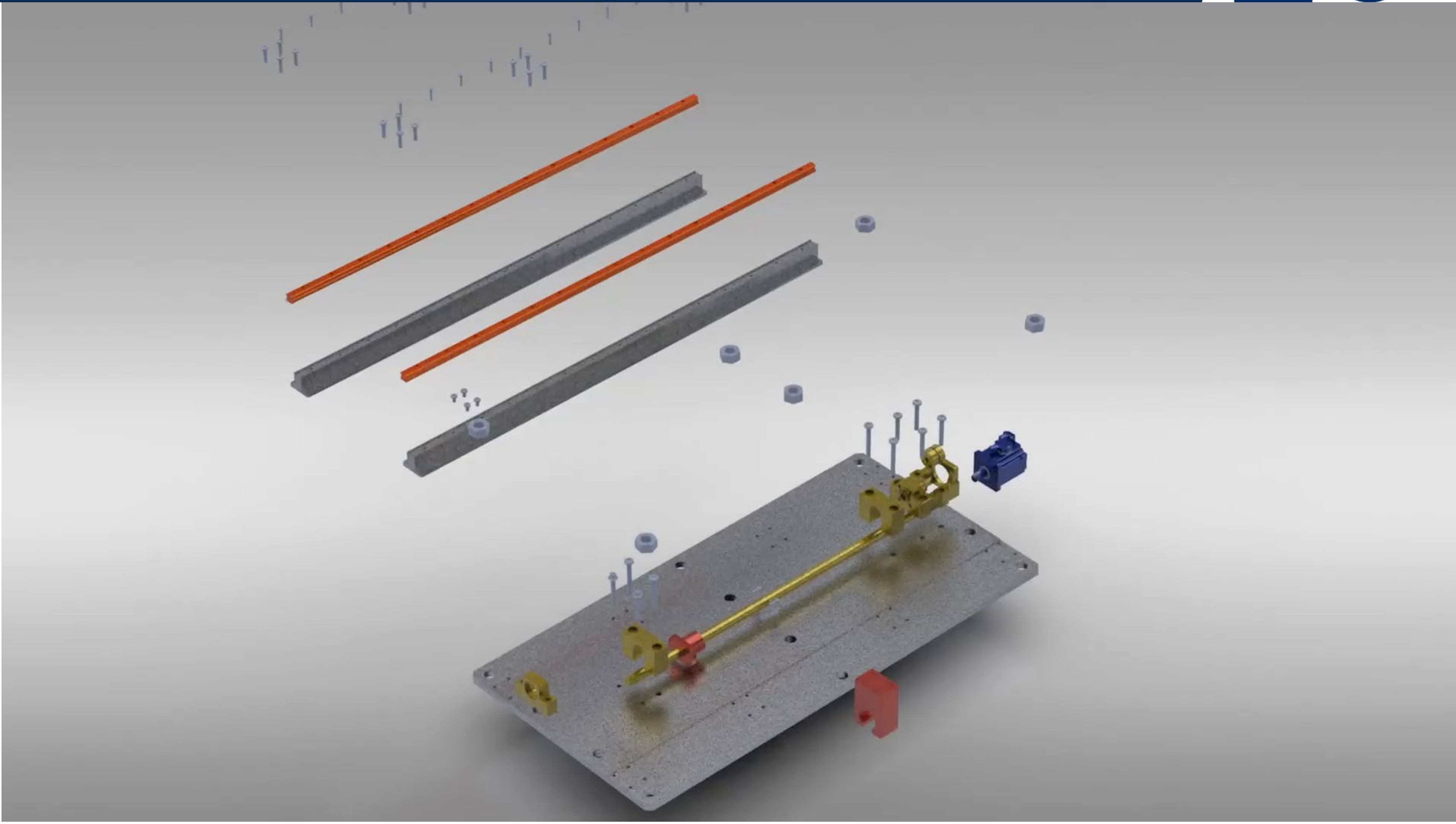


Animation (Overview)

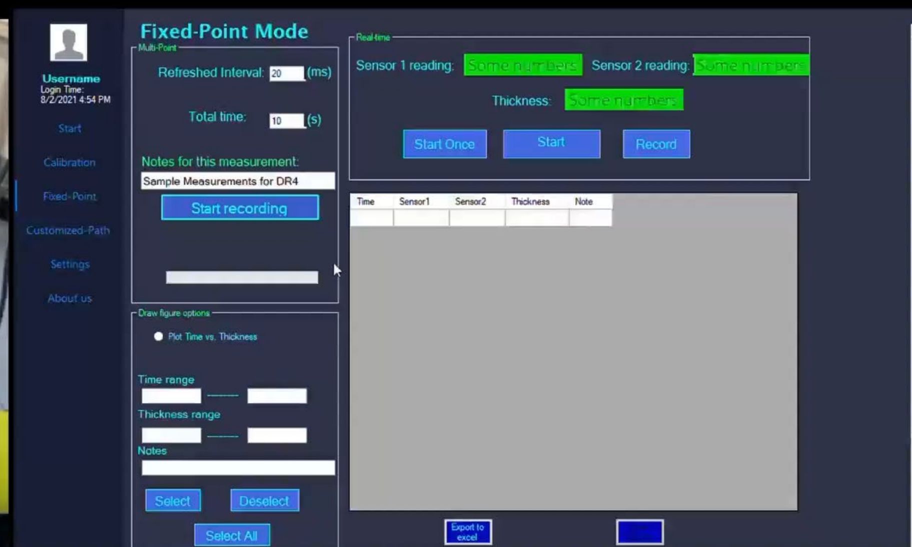


Animation (C-shaped Frame)

Animation (Baseboard)



Operation



Hardware Software

Validation Results

Recall Our Specifications:

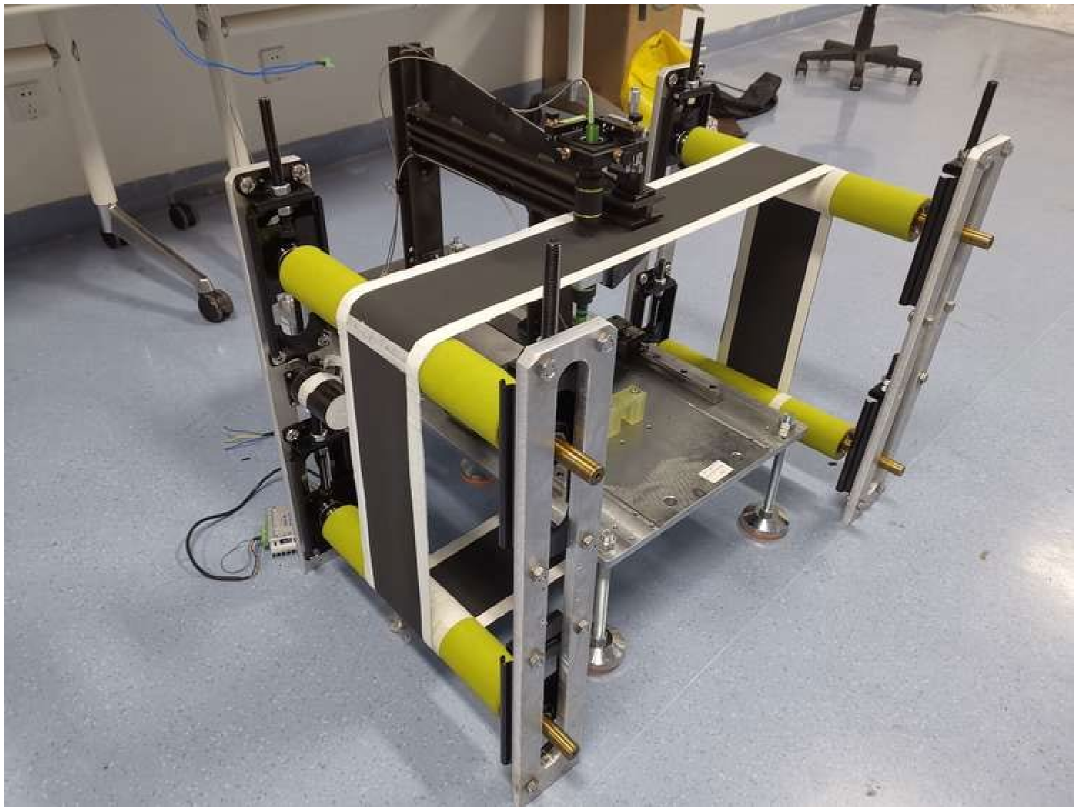
1. Low cost: < 100,000 RMB
2. Small-sized: less than 1.5 m × 1 m × 2 m
3. High precision: ± 0.5 μm
4. Good stability: pass measurement system assessment (MSA)

No experiments needed

Experiments:

1. Static measurement system assessment -> 4 (pass MSA)
2. Static measurements -> 3 (vibration < ± 0.5 μm)
3. Dynamic measurements -> 3 (periodic pattern)

Measurement System Assessment



MSA (Measurement System Assessment): an experimental and mathematical method of quantifying

- Accuracy
- Precision
- Stability

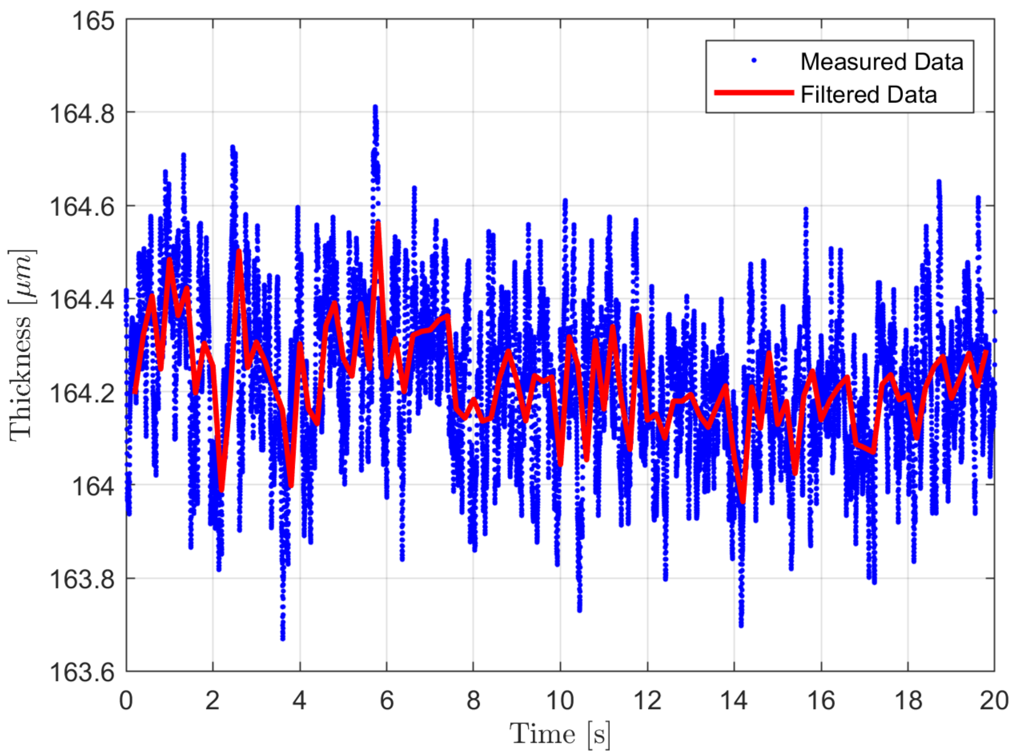
- 3 appraisers
- 4 positions (3 trials each)

Result: %GRR = 9.91% < 10% (Pass the test!)

(Standard deviation of the combined repeatability and reproducibility/ Standard deviation of the total variation)

Validation Results (Static)

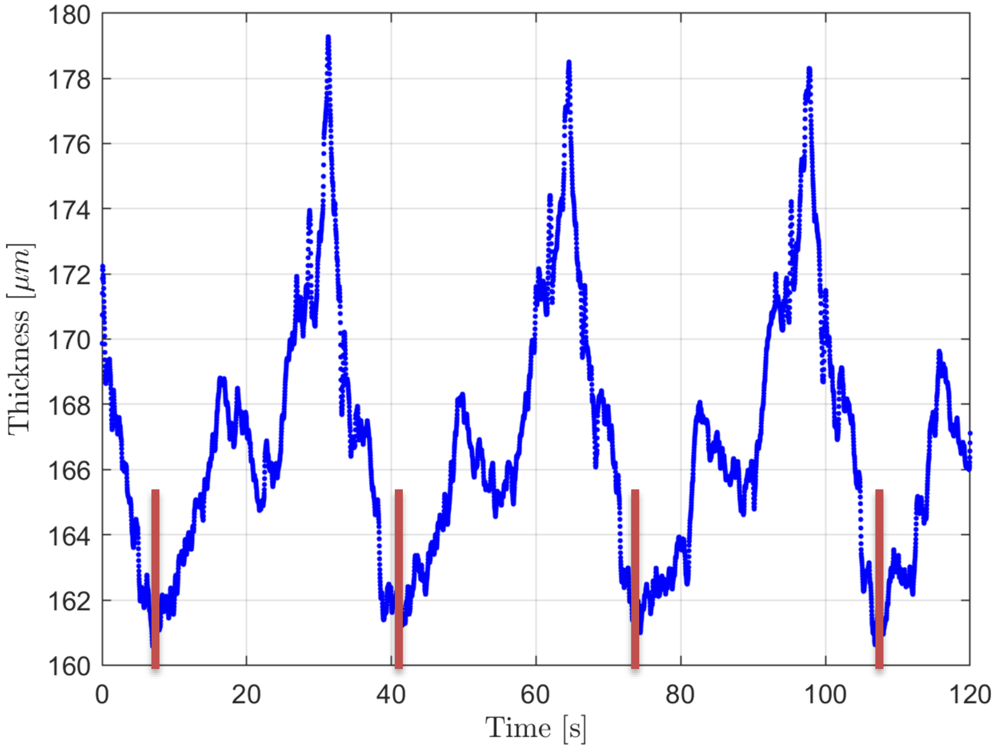
Measure the thickness of a single point

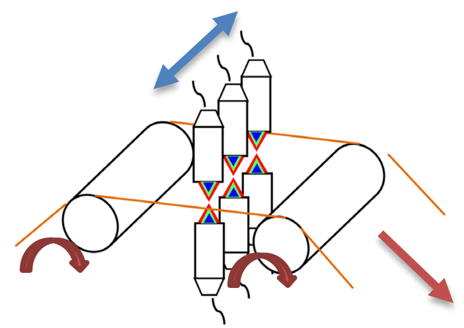


- Vibration < ± 0.5 μm after filtering

Validation Results (Dynamic)

Scan along the horizontal direction

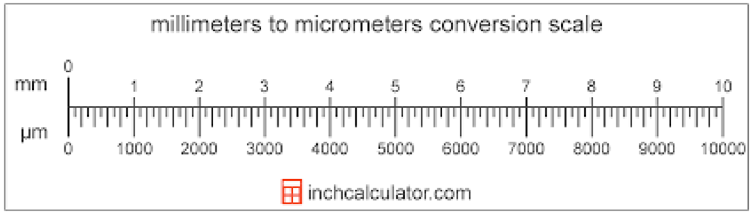




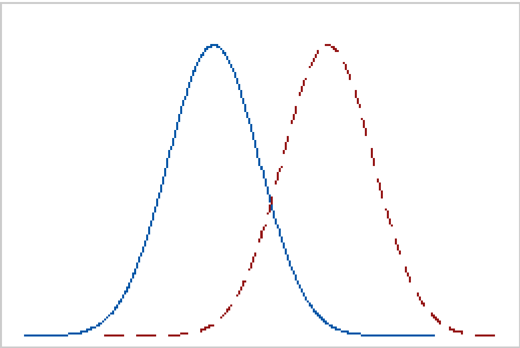
- A periodic pattern is observed!

Discussion – Strengths

Cheap



High resolution



Stable

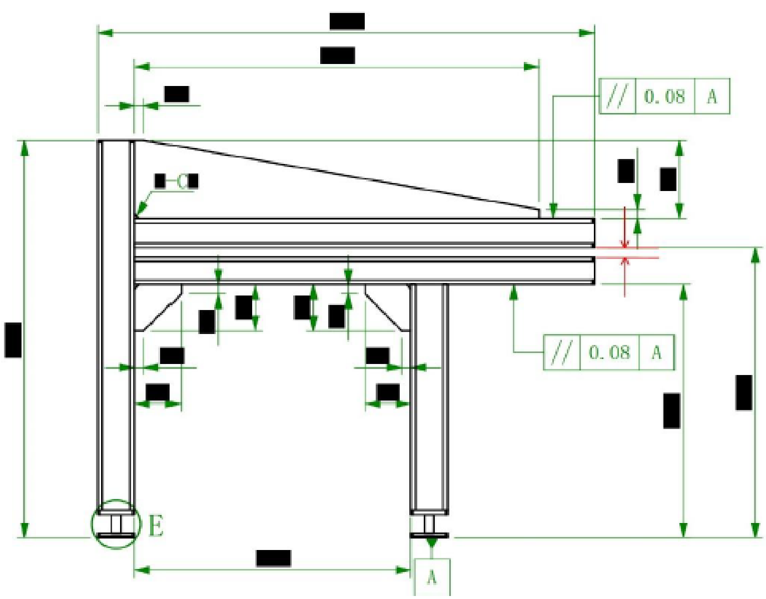
User friendly

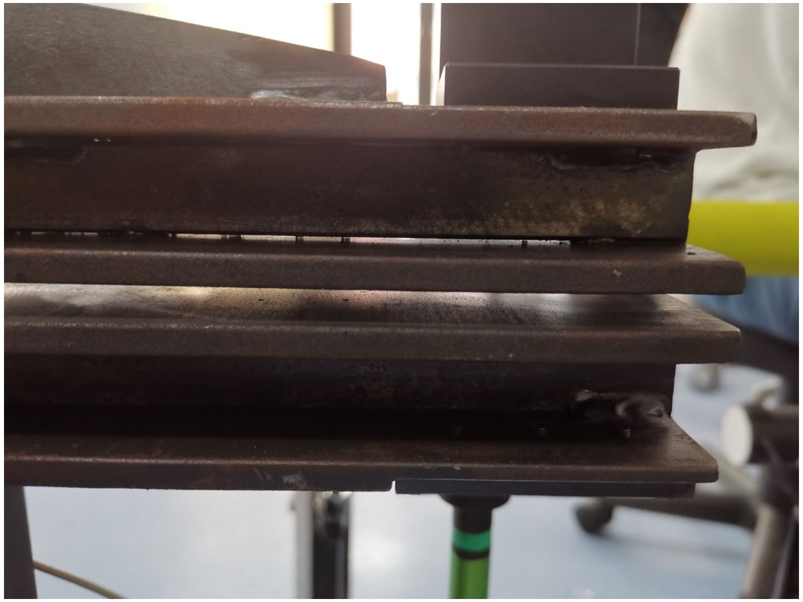
Discussion – Weaknesses

- Long manufacturing time
- Manufacturing tolerance/errors
- Influence of temperature
- Inconsistent hardware/software timestamps

Discussion – Weaknesses

Problem 1: Uncertain manufacturing tolerances





Discussion – Weaknesses

Problem 1: Uncertain manufacturing tolerances

Proposed Solution:

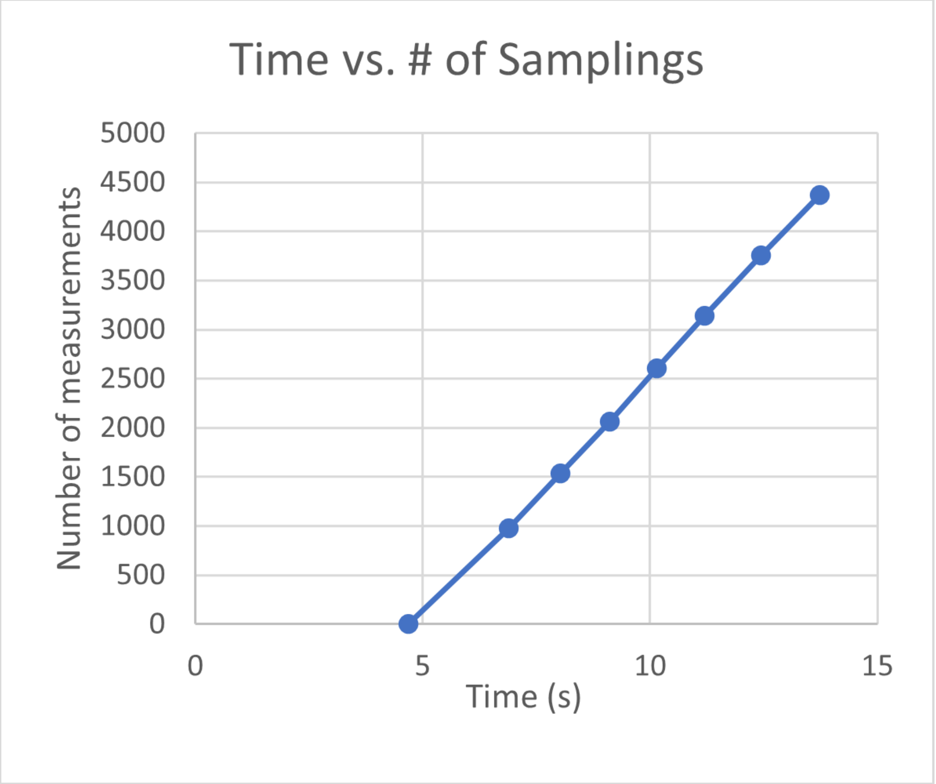
1. Bend the upper beam of the C-shaped frame upward
2. Increase the dimension between the two beams in our design

Discussion – Weaknesses

Problem 2: Inconsistent Hardware/Software timestamps

No way to fetch hardware timestamps

Software system time is not accurate enough



Discussion – Weaknesses

Problem 2: Inconsistent Hardware/Software timestamps

Proposed Solution:

1. Extend the measuring time and approximate sampling frequency
2. Request the sensor supplier to implement such features

Conclusions

Objective: non-contact thickness measuring system

- Low cost
- Small size
- High Precision

Design Solution:

- An I-beam reinforced C-shaped frame with movable mechanisms
- Two confocal displacement sensors
- Software to acquire, filter, and visualize data

Conclusions

Major Achievements:

- Pass MSA test
- Observe periodic pattern when scanning along the horizontal direction

Lessons Learned:

- Think a step further about the procedures after your design
- Testing, testing and testing!
- Slight differences can result in severe results

Q & A

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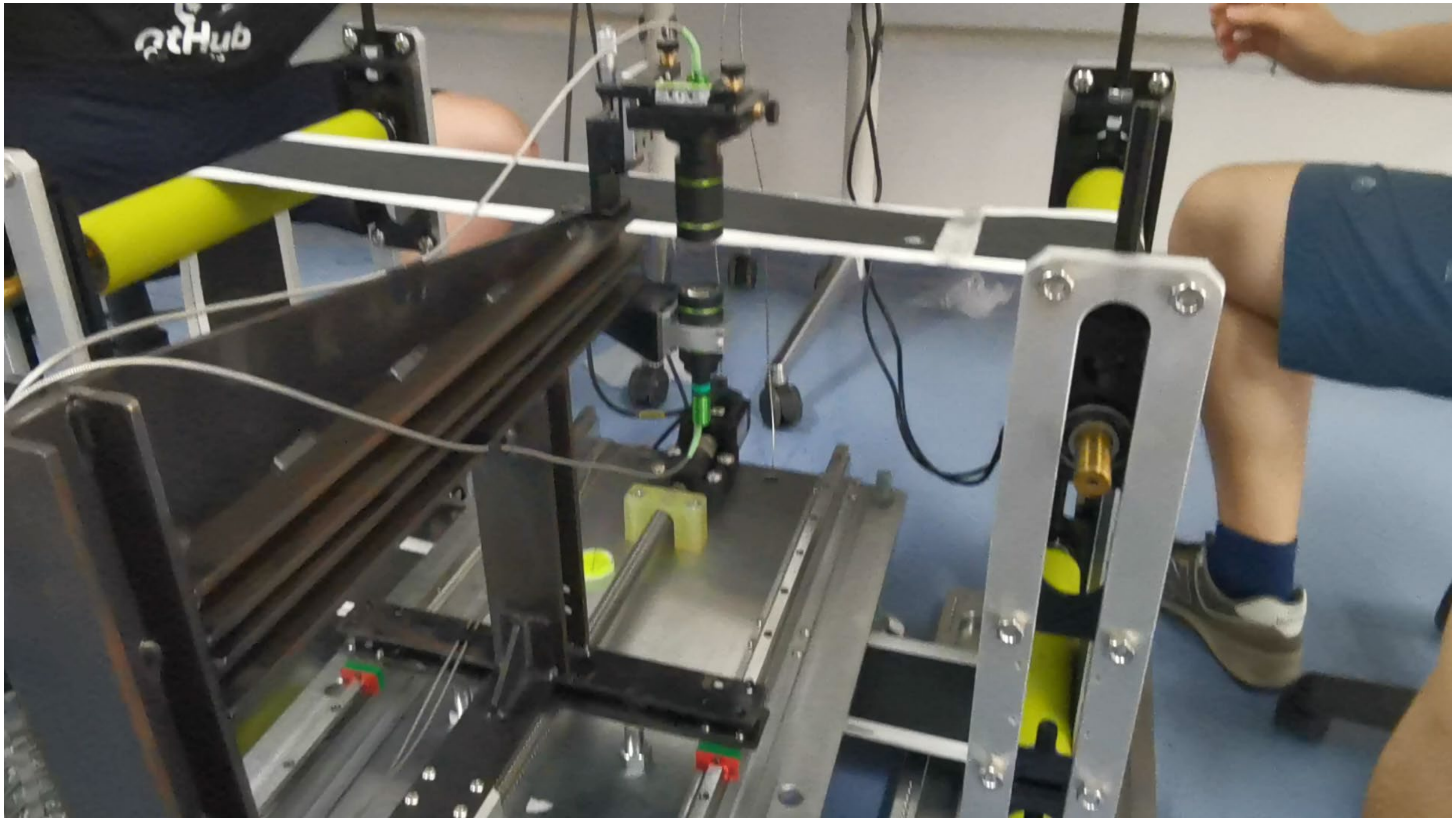
Supplementary Information

Operation (roller)



MSA Results - Raw Data

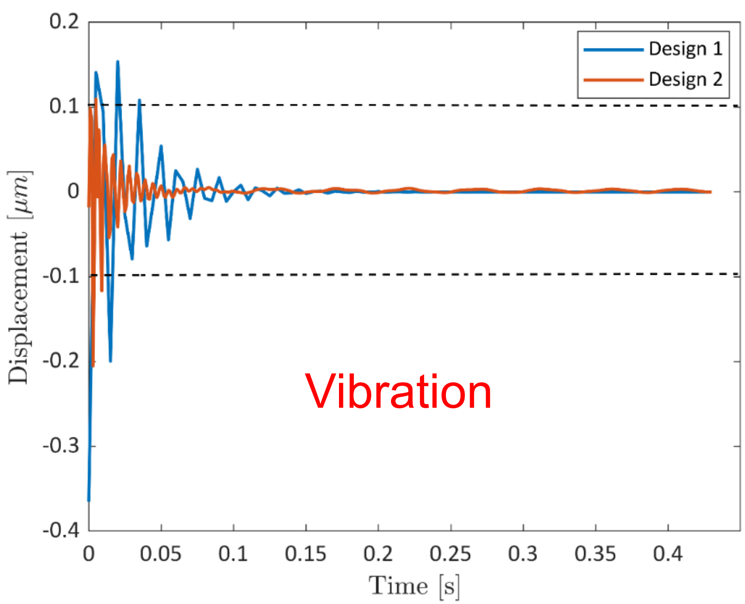
评价人/测量次数		零件 1	2	3	4	5	6	7	8	9	10	平均值	
A	1	170.7369	164.8084	158.8633	169.0813							A_1	165.87246
	2	169.9468	164.1022	158.7248	170.0763							A_2	165.71256
	3	170.5299	165.5337	158.969	169.0988							A_3	166.03284
平均值		170.40453	164.81477	158.85236	169.41881							$\bar{X}_A$	**165.87262**
极差		0.79006	1.43145	0.24418	0.99505							$\bar{R}_A$	**0.86518**
B	1	169.5293	164.7674	158.2856	168.4746							B_1	165.26421
	2	169.5293	164.7982	158.6239	168.4888							B_2	165.36004
	3	168.372	164.4889	158.7469	169.0447							B_3	165.16313
平均值		169.14351	164.68485	158.55215	168.66933							$\bar{X}_B$	**165.26246**
极差		1.15732	0.30929	0.46129	0.57013							$\bar{R}_B$	**0.62451**
C	1	168.8754	164.1	158.7663	168.6929							C_1	165.10865
	2	169.7772	164.7424	158.4052	169.4025							C_2	165.58181
	3	169.7772	165.7476	158.2463	169.9802							C_3	165.93779
平均值		169.47657	164.86332	158.4726	169.35852							$\bar{X}_C$	**165.54275**
极差		0.90173	1.64758	0.52002	1.28727							$\bar{R}_C$	**1.08915**
零件平均值		169.6749	164.7876	158.6257	169.1489							$\bar{\bar{X}}_P$ =	165.55928
零件平均值极差												R_P =	11.04917
	$\bar{\bar{R}} = (R_A + R_B + R_C)$/ Appraiser = (				0.86518	+	0.62451	+	1.08915	) /	3	=	0.85962
	$\bar{X}_{DIFF}$=	[Max $(\bar{X})_{ABC}$]	—	[Min $(\bar{X})_{ABC}$] =	165.87262	—	165.26246					=	0.61016
	UCL_R=	$\bar{\bar{R}}$	×	*D_4 =	0.85962	×	2.575					=	2.21351
	UCL_{xbar}=	$\bar{\bar{X}}p$	+	A2	×	$\bar{\bar{R}}$ =	165.559	+	1.0230	×	0.8596	=	166.43866
	LCL_{Xbar}=	$\bar{\bar{X}}p$	—	A2	×	$\bar{\bar{R}}$ =	165.559	—	1.0230	×	0.8596	=	164.67989

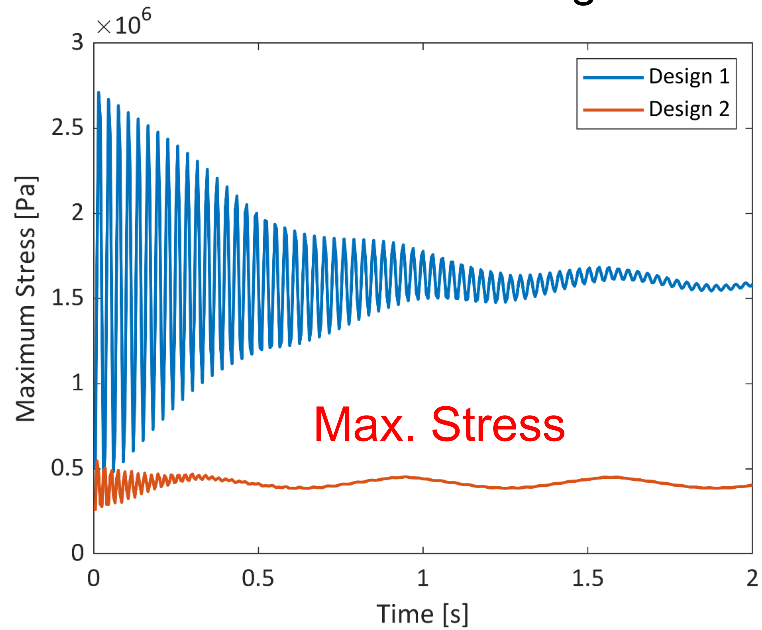
MSA Results - Report

测量单元分析			总变差%（TV）——基于零件变差
重复性—设备变差（EV）			
EV = $\bar{\bar{R}} * K_1$			% EV = 100[EV/TV]
= 0.50786	**Trial#**	**K_1**	= 8.74%
	3	0.5908	
再现性—评价人变差（AV）			
AV= $\sqrt{(\bar{X}_{DIFF} * K_2)^2 - (EV^2 / (nr))}$			% AV = 100[AV/TV]
= 0.27058	**Appraiser**	**K_2**	= 4.66%
（n =Parts，r =Trials）	3	0.5231	
重复性和再现性（GRR）			
GRR= $\sqrt{(EV^2 + AV^2)}$			**% GRR = 100[GRR/TV]**
= 0.57544			**= 9.91%**
零件变差（PV）			
PV= $R_P * K_3$ （PV=$\sqrt{TV^2 - GRR^2}$）	**Part #**	**K_3**	% PV = 100[PV/TV]
= 5.77982	3	0.5231	= 99.51%
总变差（TV）			区别分类数（ndc）
TV= $\sqrt{(GRR^2 + PV^2)}$ **(TV= Total Tolerance/6)**			ndc= 1.41*PV/GRR
= 5.808395006			= 14

Design Analysis (details)

Use Finite Element Analysis to simulate the vibration (left) and the maximum stress (right) for previous and current versions of design.





For current design compared with previous one:

- Faster decaying vibration amplitude, better stability;
- Smaller maximum stress, better reliability;
- Total vibration < 0.x μm (target resolution) after 0.025 s.