Background Introduction

Zhengrui Tao

School of Mechanical Engineering Shanghai Jiao Tong University
Manufacturing Technology Laboratory

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Address: Building of Mechanical Engineering Room D300C, No 800, Dongchuan Rd.
MinHang District, Shanghai, 200240, P.R.China
☎: (+86) 186-2180-8762; ✉: *taozhengrui@sjtu.edu.cn; zhengrui.tao@hotmail.com*.

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I. Basic Introduction

Zhengrui Tao

Education Background

✓ **Shanghai Jiao Tong University** **Sept. 2017 - June 2020**

M.Sc. in Mechanical Engineering

Major GPA: **3.61**/4.00, Overall GPA: **3.75**/4.00

✓ **Harbin Institute of Technology** **Sept. 2013 - June 2017**

B.Eng. in Mechanical Design, Manufacturing and Automation,

Major GPA: **92.30**/100, Overall GPA:**91.80**/100

Research interests

1) Smart Manufacturing ; 2) Prognostic and Health Management

https://zhengruitao.github.io/

Honors & Awards

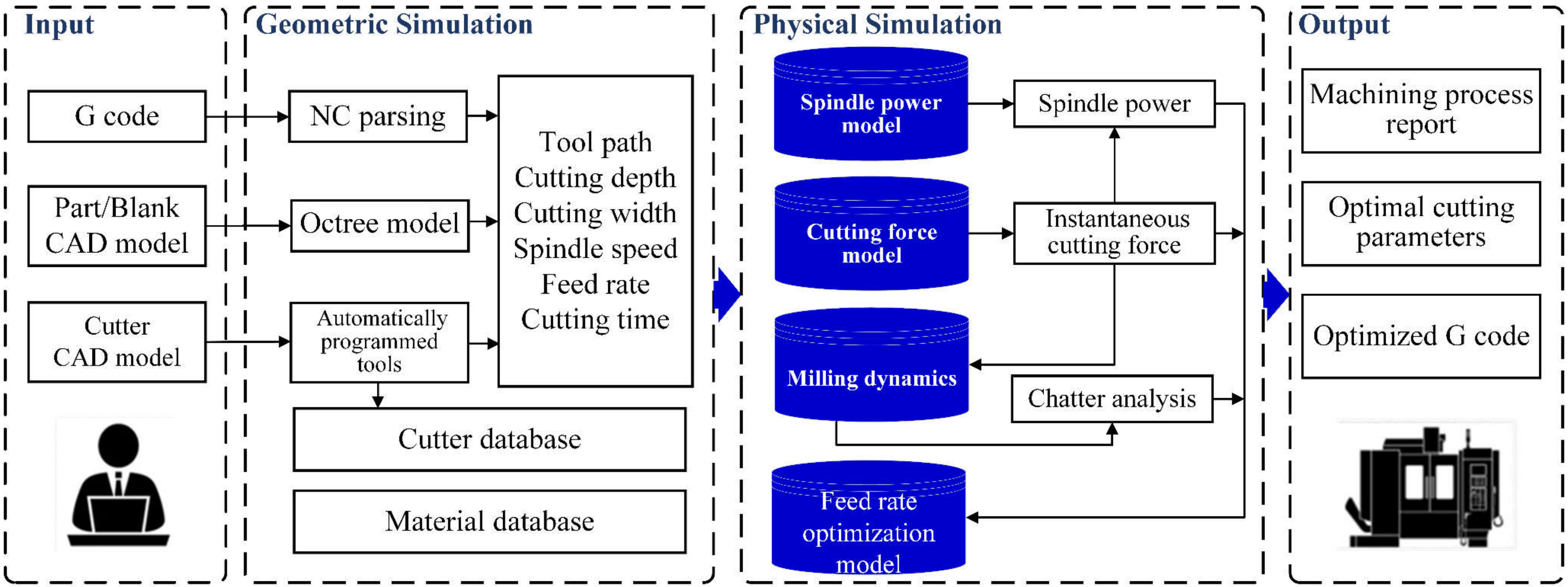
- **Shanghai Outstanding Graduates (Top 1%)** **2019**
- **National Graduate Scholarship (Top1%)** **2019**
- **Sandvik Coromant Scholarship (Top 3%)** **2018**
- **Shandong Province Outstanding Graduates (Top 2%)** **2017**
- **National Undergraduate Scholarship (Top1%)** **2016**

II. Research

Virtual Machining System: Chatter Stability Analysis & Feedrate Optimization

Background: *Raising machining efficiency and reducing costs are becoming key factors for manufacturing enterprises to maintain competitiveness. CAD and CAM are integrated for tool path generation and feedrate scheduling based on material removal rate and chatter stability.*

Key words: Geometric simulation; Chatter stability analysis; Cutting parameters optimization



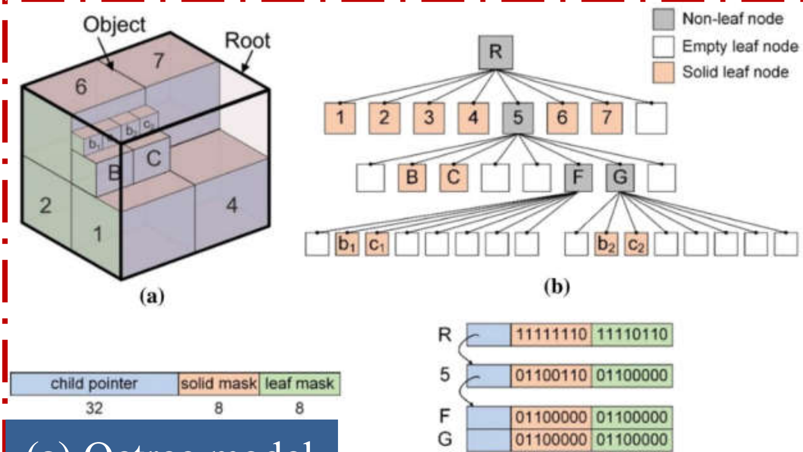
Challenges:

(a) Identify cutter-workpiece engagement (CWE)

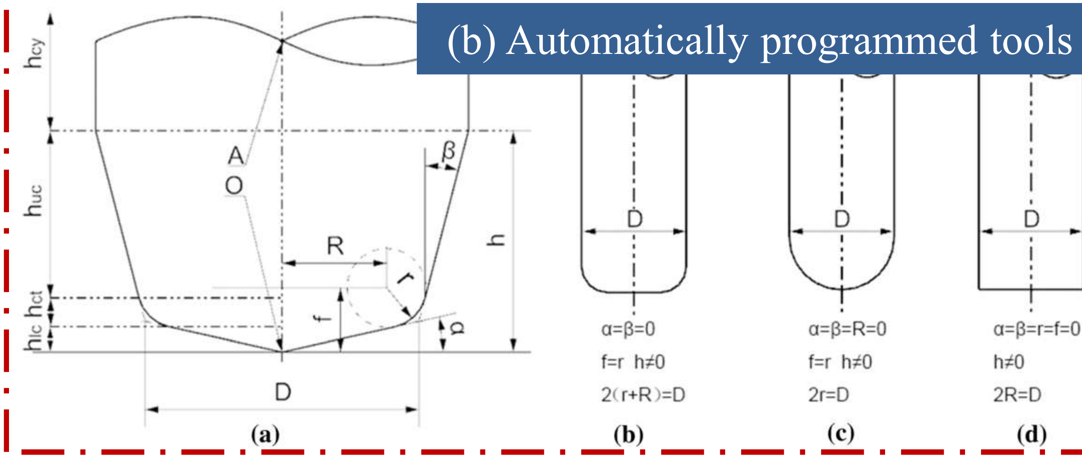
(b) Model physical milling process

(c) Optimize the feedrate

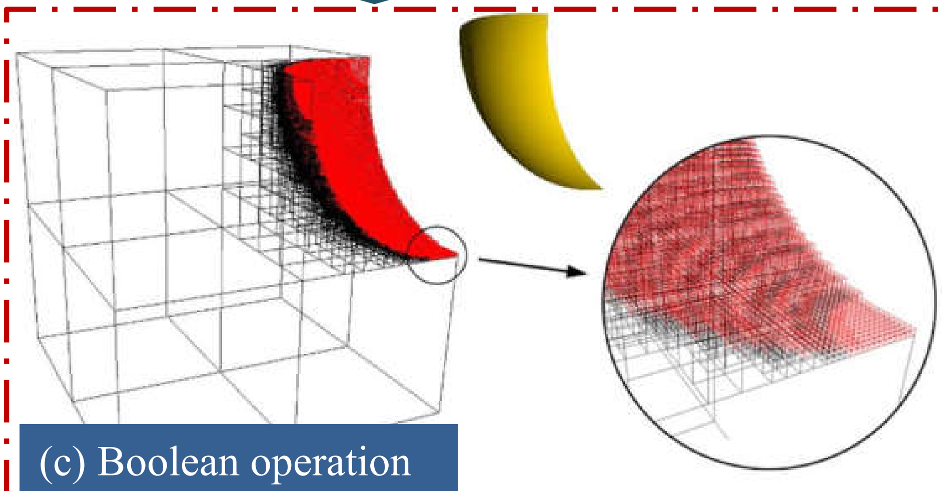
Geometric Simulation



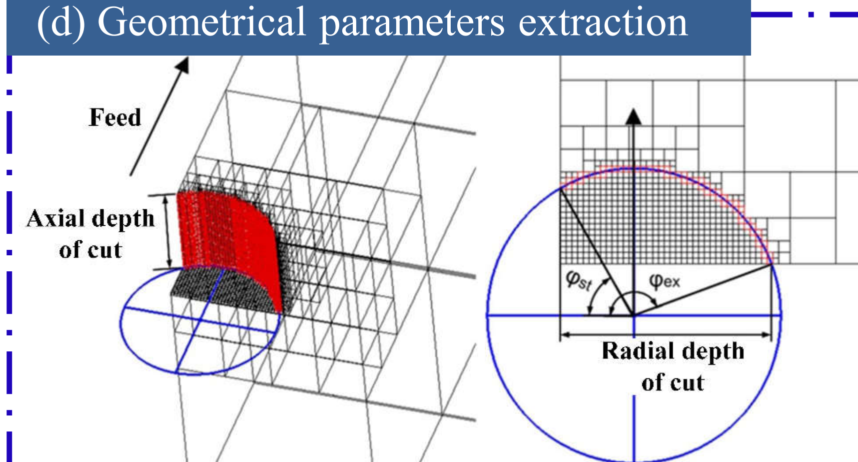
(a) Octree model



(b) Automatically programmed tools



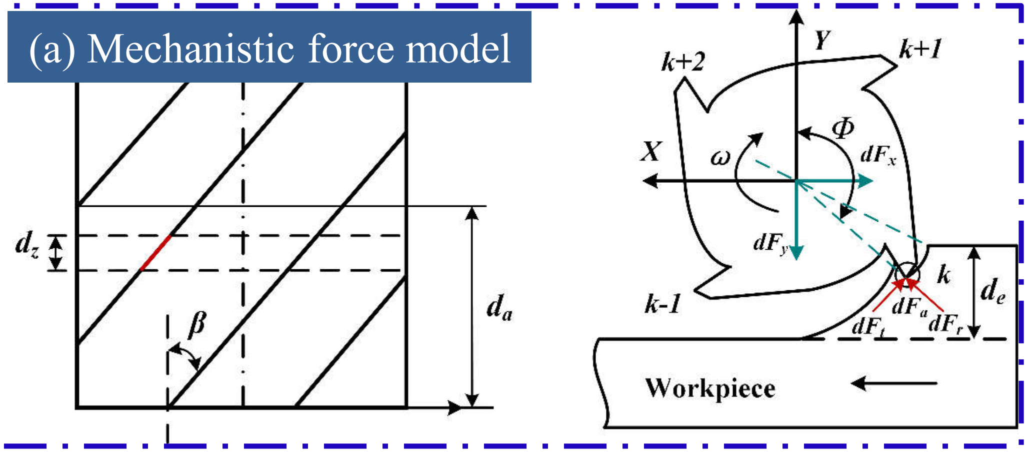
(c) Boolean operation



(d) Geometrical parameters extraction

Physical Simulation - Cutting Forces

(a) Mechanistic force model



Cutting coefficients for plowing forces

$$\begin{cases} dF_{t,j}(\phi,z) = (K_{tc}h_j(\phi,z) + K_{te})ds \\ dF_{r,j}(\phi,z) = (K_{rc}h_j(\phi,z) + K_{re})ds \\ dF_{a,j}(\phi,z) = (K_{ac}h_j(\phi,z) + K_{ae})ds \end{cases}$$

Cutting coefficients for shearing forces

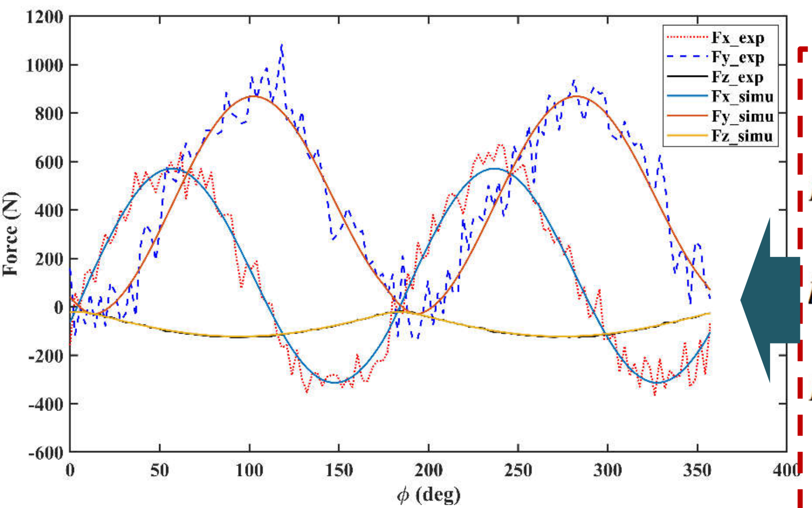
(b) Determine cutting force coefficients

$$\bar{F}_x = \left[\frac{N_t b f_t}{8\pi}(-k_t\cos(2\phi) + k_n(2\phi - \sin(2\phi))) + \frac{N_t b}{2\pi}(k_{te}\sin(\phi) - k_{ne}\cos(\phi))\right]_{\phi_s}^{\phi_e}$$

$$\bar{F}_y = \left[\frac{N_t b f_t}{8\pi}(k_t(2\phi - \sin(2\phi)) + k_n\cos(2\phi)) - \frac{N_t b}{2\pi}(k_{te}\cos(\phi) + k_{ne}\sin(\phi))\right]_{\phi_s}^{\phi_e}$$

$$\bar{F}_z = \left[\frac{N_t b}{2\pi}(k_a f_t\cos(\phi) - k_{ae}\phi)\right]_{\phi_s}^{\phi_e}$$

Average Force, Linear Regression Method



(c) Experiment & Simulation

Physical Simulation - Chatter Stability Analysis

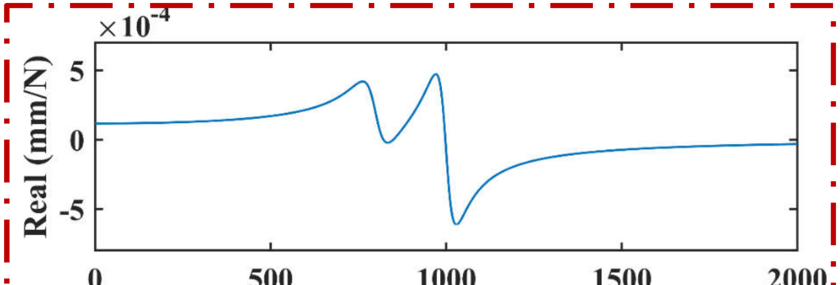
$$\begin{pmatrix}X_j\\ Y_j\end{pmatrix} = \begin{bmatrix}\mathrm{FRF}_{xx} & \mathrm{FRF}_{xy}\\ \mathrm{FRF}_{yx} & \mathrm{FRF}_{yy}\end{bmatrix}\begin{pmatrix}F_x\\ F_y\end{pmatrix}\mathrm{e}^{i\omega_c t} = \begin{bmatrix}\mathrm{FRF}_{xx} & 0\\ 0 & \mathrm{FRF}_{yy}\end{bmatrix}\begin{pmatrix}F_x\\ F_y\end{pmatrix}\mathrm{e}^{i\omega_c t}$$

$$[A_0][\mathrm{FRF}] = \frac{N_t}{2\pi}\begin{bmatrix}\alpha_{xx} & \alpha_{xy}\\ \alpha_{yx} & \alpha_{yy}\end{bmatrix}\begin{bmatrix}\mathrm{FRF}_{xx} & 0\\ 0 & \mathrm{FRF}_{yy}\end{bmatrix} = \frac{N_t}{2\pi}\begin{bmatrix}\alpha_{xx}\mathrm{FRF}_{xx} & \alpha_{xy}\mathrm{FRF}_{yy}\\ \alpha_{yx}\mathrm{FRF}_{xx} & \alpha_{yy}\mathrm{FRF}_{yy}\end{bmatrix} = \frac{N_t}{2\pi}[\mathrm{FRF}_{or}]$$

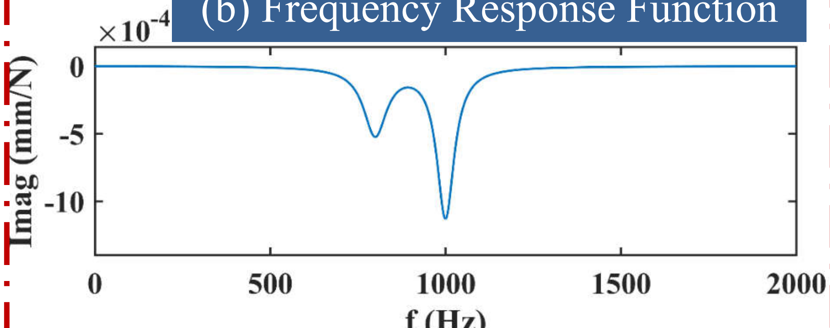
$$b_{\lim} = -\frac{2\pi}{N_t K_t}\Lambda_{\mathrm{Re}}\left(1 + \frac{\Lambda_{\mathrm{Im}}}{\Lambda_{\mathrm{Re}}}\frac{\sin(\omega_c\tau)}{(1-\cos(\omega_c\tau))}\right) = -\frac{2\pi}{N_t K_t}\Lambda_{\mathrm{Re}}(1+\kappa^2)$$

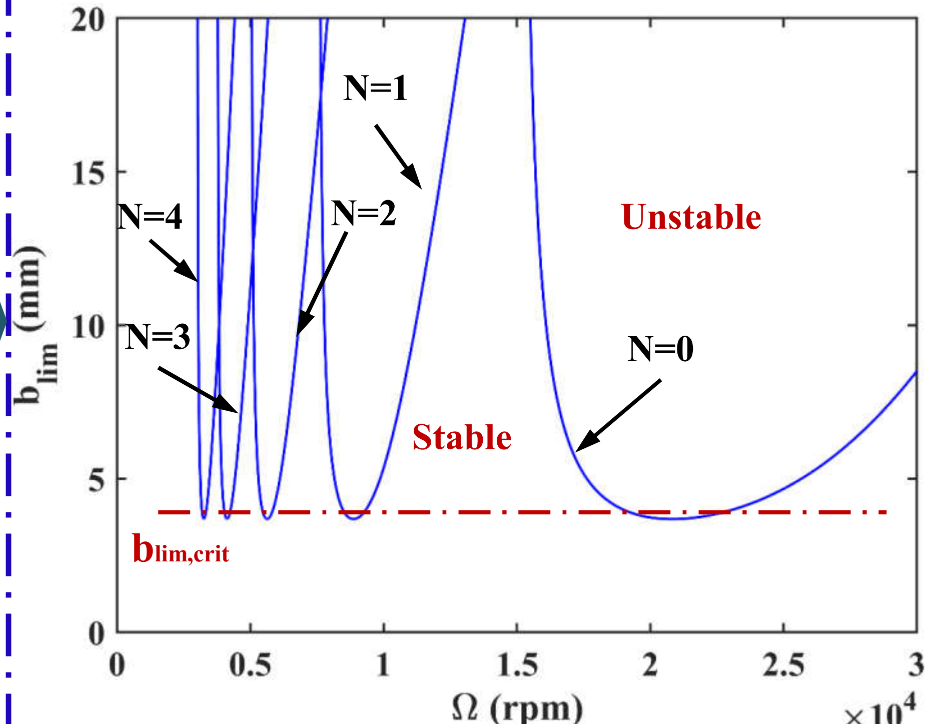
$$\Omega = \frac{60}{N_t\tau}\ (\mathrm{rpm})$$

(a) Fourier series approach



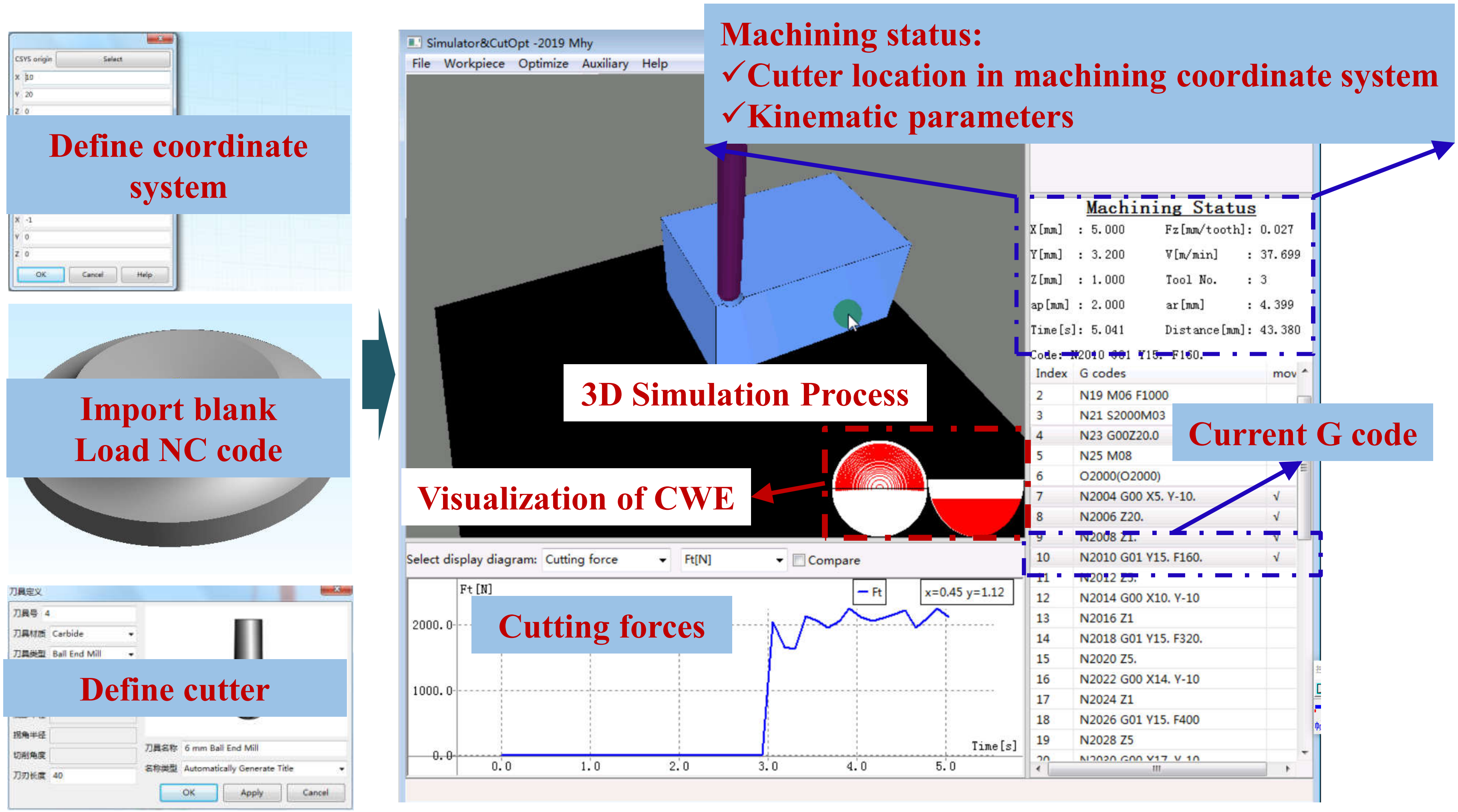
(b) Frequency Response Function





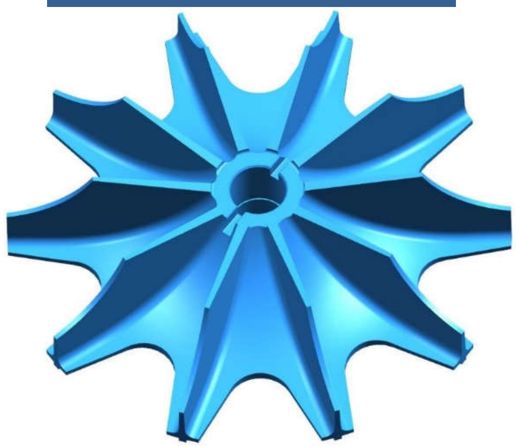
(c) Stability Lobe Diagram
N - integer number of waves between teeth

Overview - Main Application Steps & User Interface



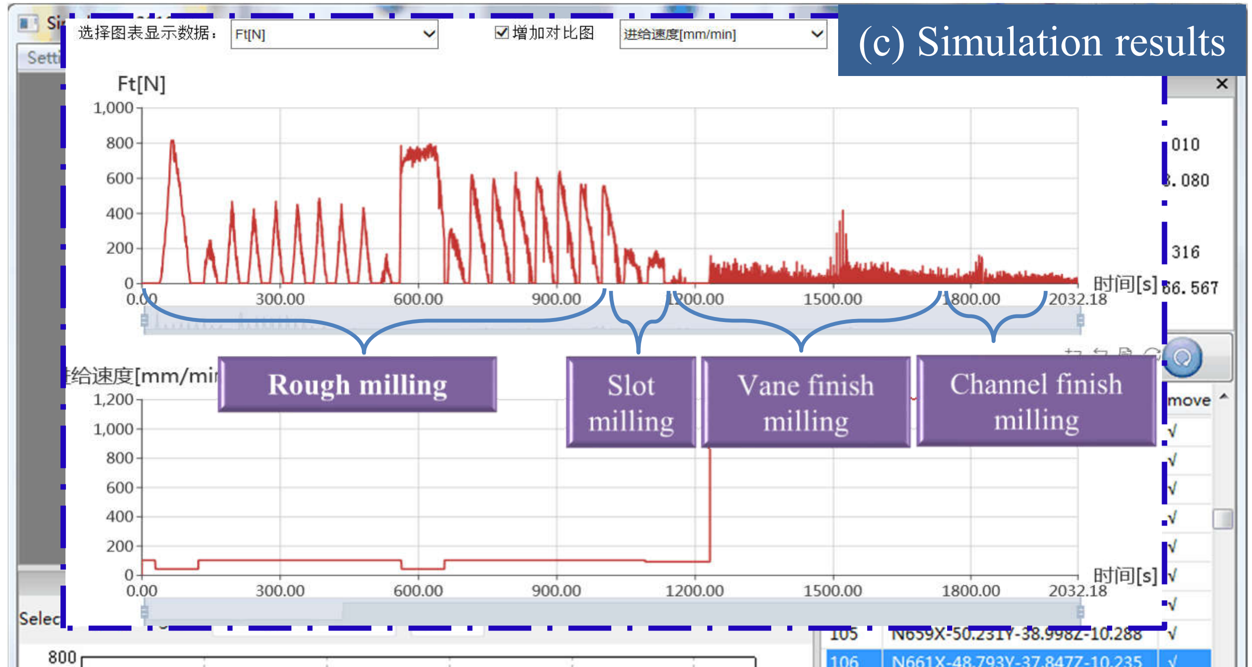
Case Study - Turbine with 10 vane channels

(a) Turbine



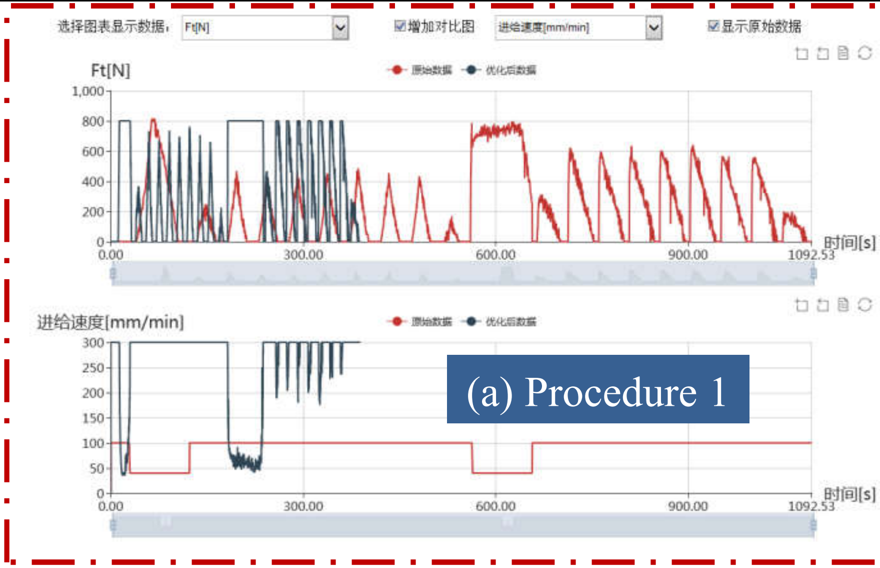
(b) Workpiece blank

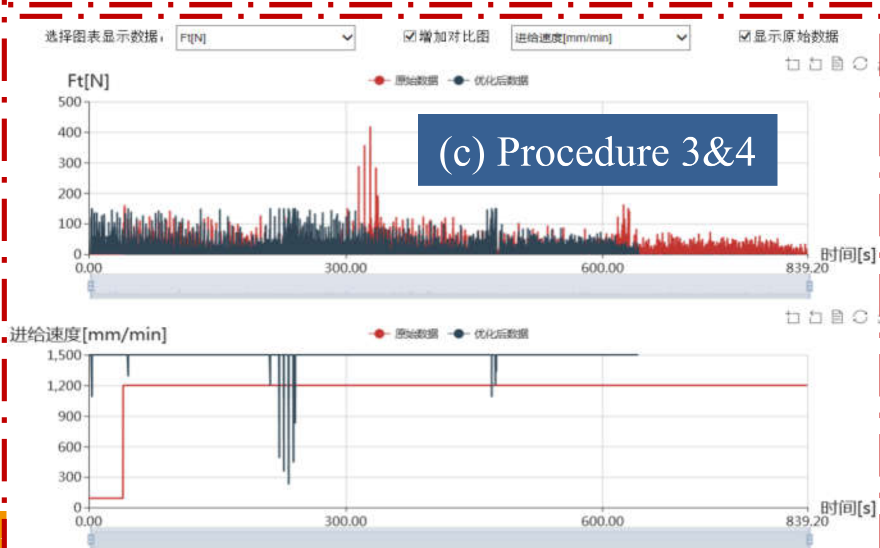
(c) Simulation results



Procedure	Detail	Cutter	Machining time
1	Rough milling	D8R1	1092s (18.2min)
2	Slot milling	D8R1	100s (1.67min)
3	Vane finish milling	D6R3	635s (10.6min)
4	Channel finish milling	D6R3	204s (3.4min)

Case Study – Turbine with 10 vane channels

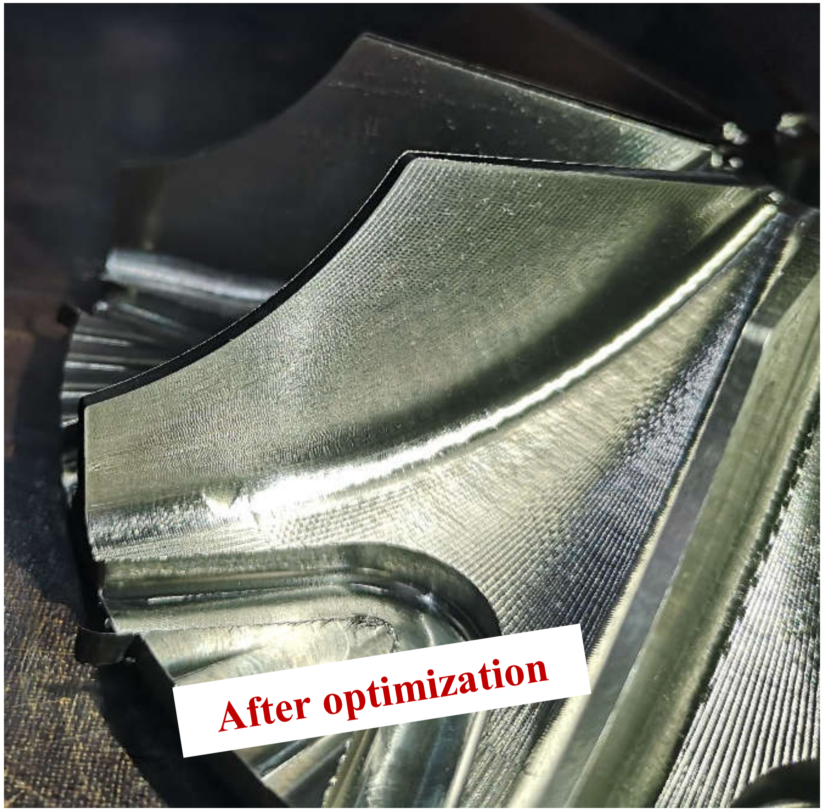




Procedure	Machining time	Optimized machining time	Efficiency improvement
1	1092s (18.2min)	390s (6.5min)	64%
2	100s (1.67min)	62s (1.03min)	61%
3	635s (10.6min)	641s (10.7min)	24%
4	204s (3.4min)		

Average cycle time reduced by 43%

Case Study – Turbine with 10 vane channels



Surface finish improved 7.4-fold

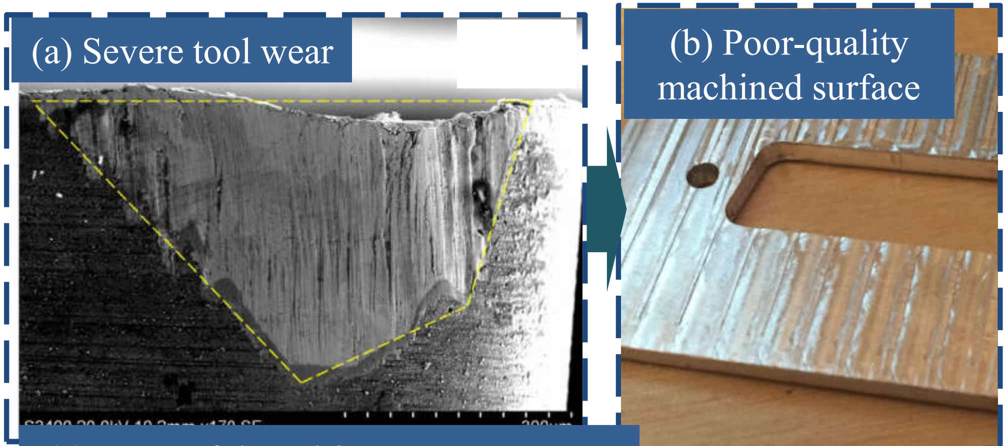
Tool Condition Monitoring: Diagnostics, Prognostics, and Remaining Useful Life Prediction

Background: *In high-performance NC machining, tool condition monitoring and fault diagnosis are widely needed. Accurate tracking of tool status and timely tool change are the key factors to ensure machining quality and improve productivity.*

Key words: Diagnostics; Prognostics; Remaining Useful Life Prediction

(a) Severe tool wear

(b) Poor-quality machined surface



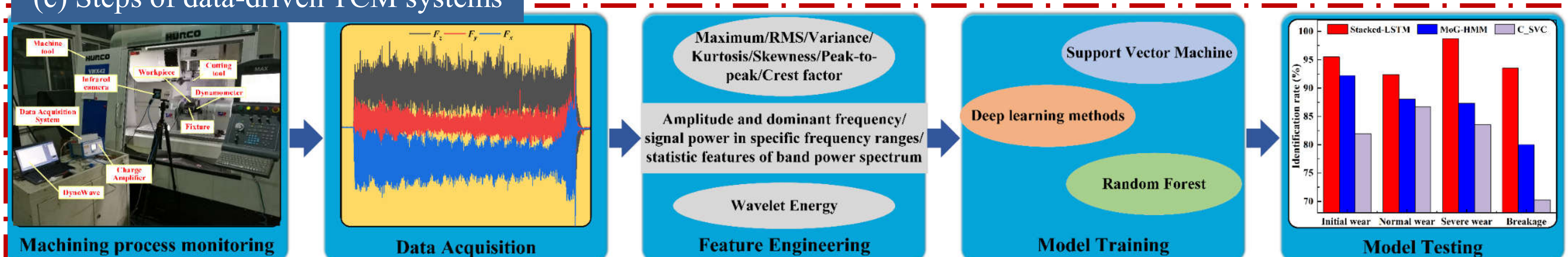
Traditional Solution

- **Cumulative cutting length, machining time, chip color and cutting noise**
- **Machine shutdown and directly check the cutting edge status**

Existing Problems

- **Tool replacement is conducted too early and waste tool life**
- **Unnecessary downtime and affect work procedure schedule**

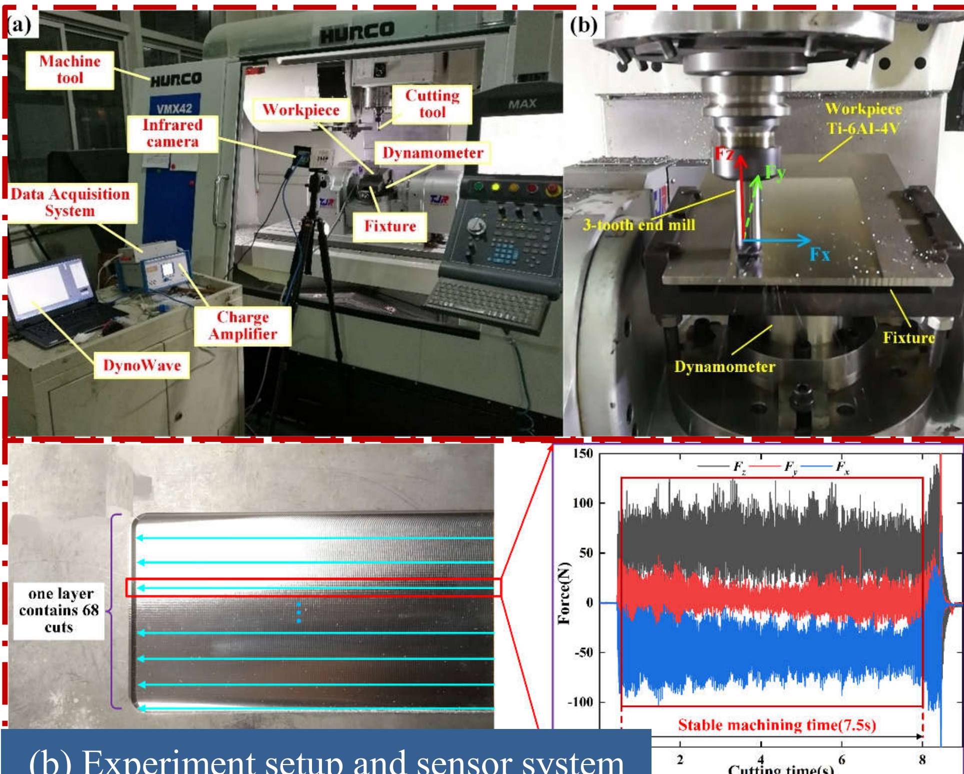
(c) Steps of data-driven TCM systems



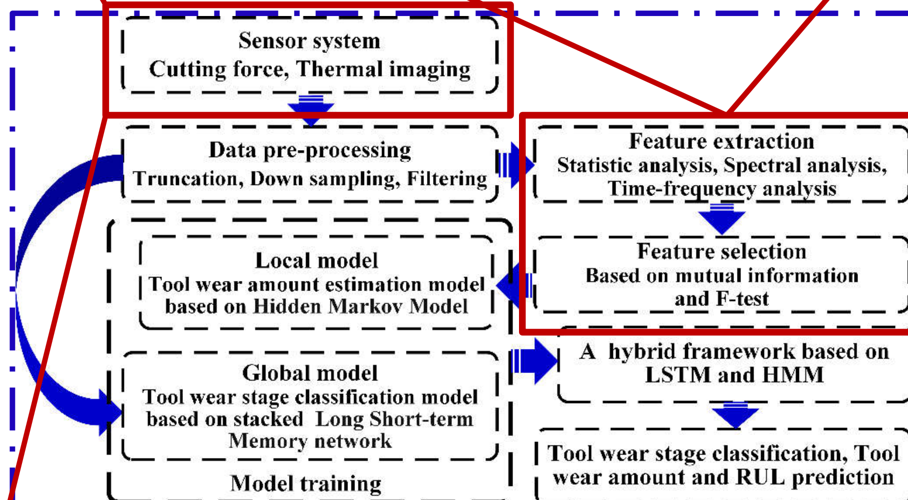
Tool condition monitoring based on long short-term memory and hidden Markov model hybrid framework

Time domain			Frequency domain	
Root mean square (*rms*) Standard deviation (*std*)	Skewness (skew) Kurtosis (*kurt*)	Maximum (*max*) Peak-to-Peak (*p-p*)	Fast Fourier Transform (*fft*) Spectral Skewness (*skew*)	Spectral Kurtosis (*kurt*) Spectral Entropy (*entr*)

Time–frequency domain
Wavelet Energy (*WT*)

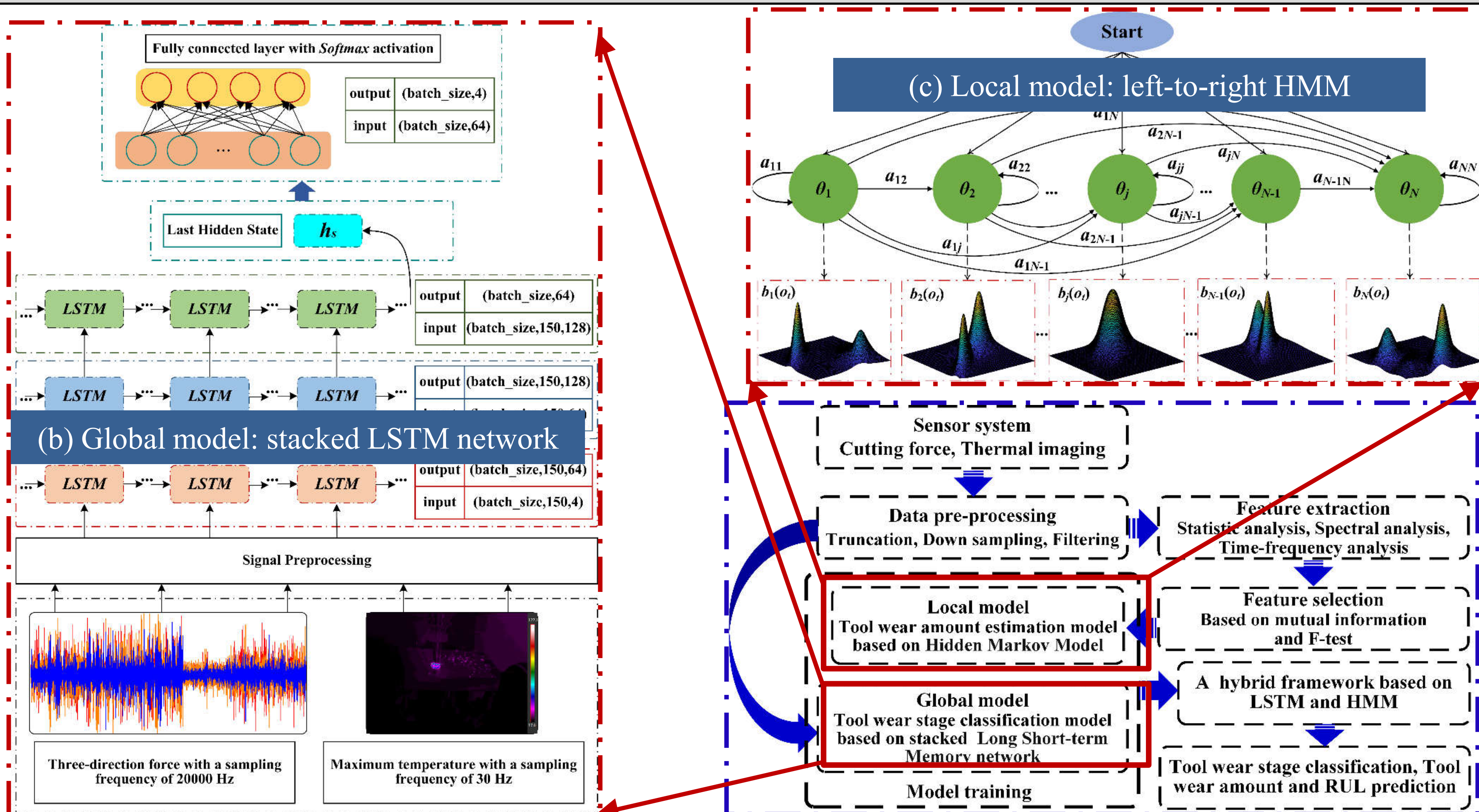


(b) Experiment setup and sensor system



(a) Technical framework diagram

Tool condition monitoring based on long short-term memory and hidden Markov model hybrid framework



(a) Technical framework diagram

Tool condition monitoring based on long short-term memory and hidden Markov model hybrid framework

(a) Tool wear stage classification accuracy

Testing dataset	Wear stage	Methods			
		sLSTM network	3-layers vanilla RNN	Feedforward NN	SVC
C1	Initial	**0.9549**	0.9123	0.8039	0.8188
	Normal	**0.9238**	0.8712	0.8427	0.8878
	Severe	**0.9875**	0.863	0.7921	0.8455
	Breakage	**0.9351**	0.7903	0.7	0.7128
	Average	**0.9503**	0.8592	0.7847	0.8162
C2	Initial	**0.9687**	0.8944	0.8125	0.8153
	Normal	**0.9528**	0.922	0.8452	0.8864
	Severe	**0.9612**	0.8635	0.8012	0.8323
	Breakage	**0.9345**	0.9324	0.8542	0.8645
	Average	**0.9543**	0.9031	0.8283	0.8496
C3	Initial	**0.942**	0.892	0.8459	0.8945
	Normal	**0.9512**	0.798	0.7625	0.7928
	Severe	**0.9189**	0.7355	0.6985	0.7315
	Breakage	**1**	0.7563	0.7632	0.8345
	Average	**0.953**	0.7955	0.7675	0.8133
Overall average		**0.9525**	0.8526	0.7935	0.8264

(b) Wear amount and RUL Prediction performance

$$MSE = \frac{1}{T_c}\sum_{c=1}^{T_c}[Wear_{real}(c) - \widehat{Wr}_m(c)]^2$$

Methods	*MSE*			
	C1	C2	C3	average
LSTM-HMM	**6.4197**	**10.6058**	**13.5193**	**10.1816**
CNN	190.613	50.3125	258.779	166.568

$$Er_c = RUL_{Real}(c) - RUL_{Prediction}(c)$$

$$S_c = \begin{cases} exp^{-\ln(0.5)\cdot(Er_c/30)}, & if\ Er_c \le 0 \\ exp^{+\ln(0.5)\cdot(Er_c/50)}, & else \end{cases}$$

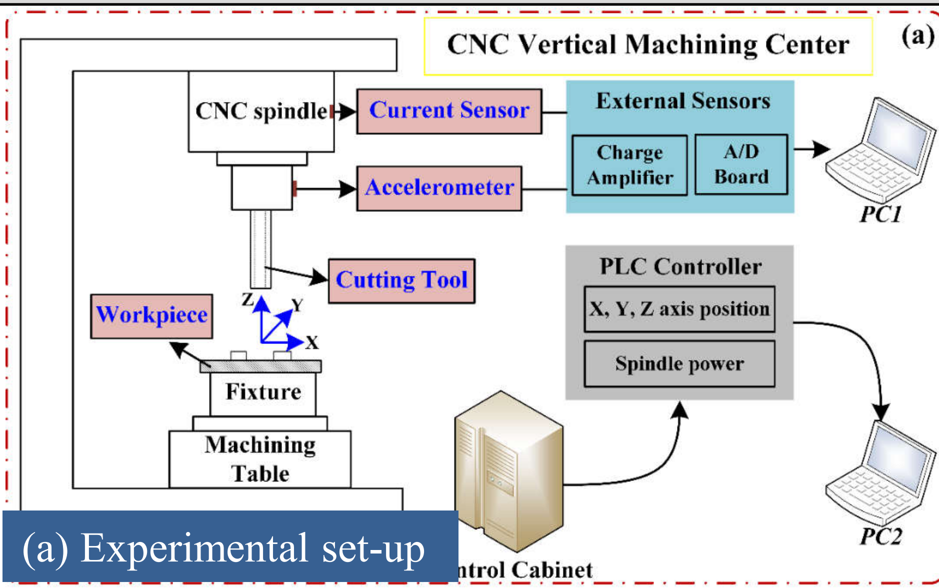
$$Accuracy = \frac{1}{T_c}\sum_{c=1}^{T_c} e^{-|Er_c|/RUL_{real}(c)}$$

$$Score = \frac{1}{T_c}\sum_{c=1}^{T_c}(100 \times S_c)$$

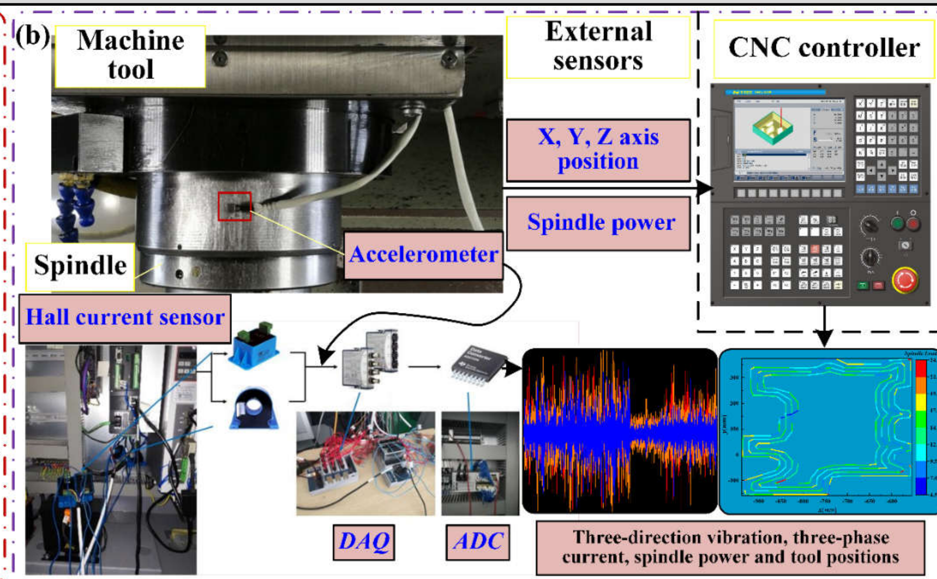
Methods	*Score*			
	C1	C2	C3	average
LSTM-HMM	**93.12**	**88.87**	**89.81**	**90.6**
CNN	84.68	88.24	80.26	84.39

Methods	*Accuracy*			
	C1	C2	C3	average
LSTM-HMM	**0.9706**	**0.9399**	**0.9475**	**0.9527**
CNN	0.8625	0.9297	0.8269	0.873

Remaining useful life prediction model combining CNN with stacked bidirectional and unidirectional LSTM network



(a) Experimental set-up



(c) Sensor system

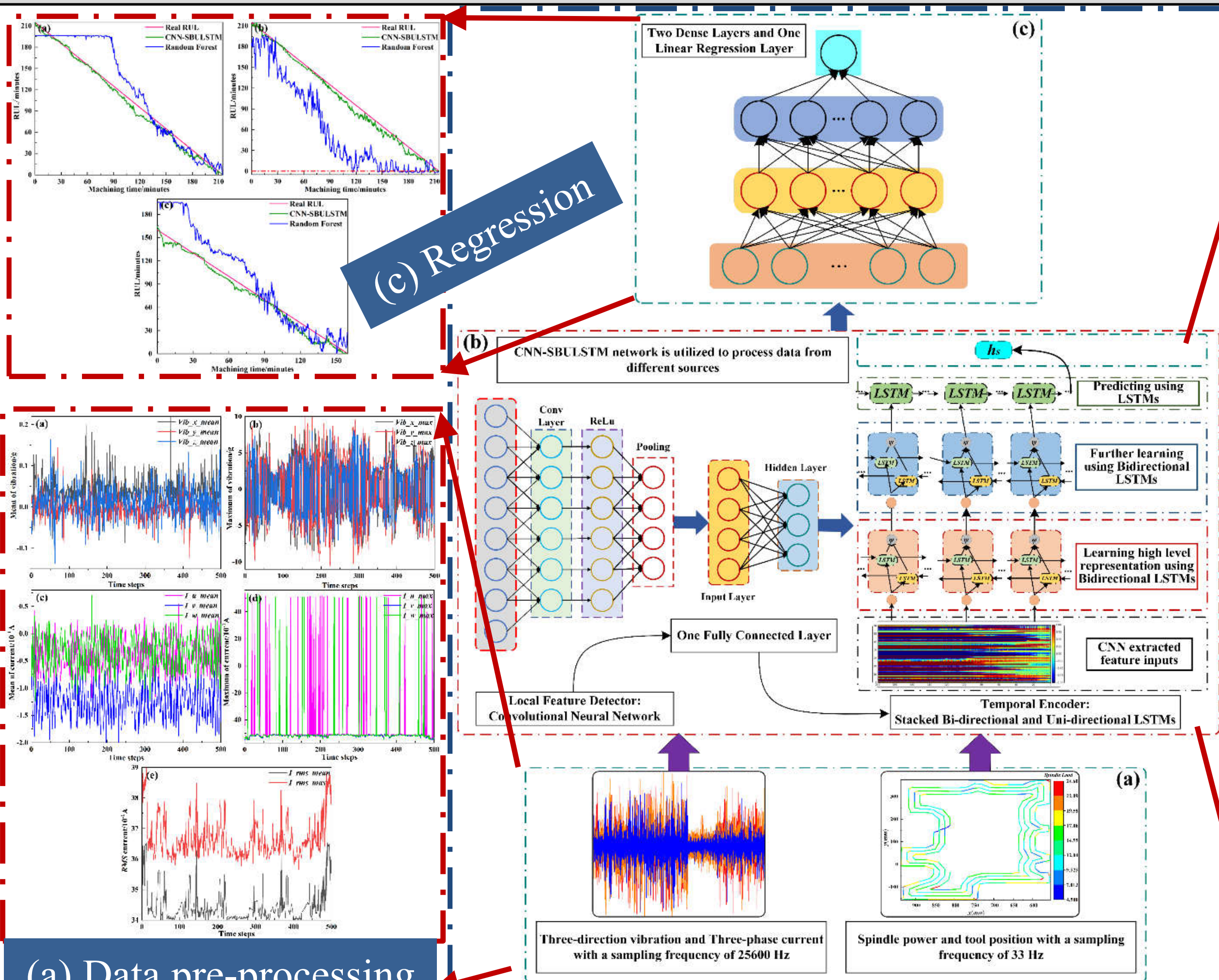
Machining smartphone backplate under dry milling operation

(b) Cutting parameters

No.	Cutting speed (m/min)	Feed (mm/z)	Cutting depth (mm)	Cutting width (mm)
1	75	0.03	1.2	2
2	75	0.04	1.2	2
3	50	0.03	1.2	2

Sensor	Signal	Description
Accelerometer	*Vib_x*, *Vib_y*, *Vib_z*	Spindle vibration
Hall Effect Current Transducer	*I_u*, *I_v*, *I_w*	AC spindle motor current
	I_rms	*RMS* of three-phase AC
PLC controller	*Pos_x*, *Pos_y*, *Pos_z*	Axes position
	Pow	Spindle power

CNN-SBULSTM network-based tool remaining useful life prediction system scheme



(b) Feature extraction and pattern recognition

Three-layers CNN is firstly utilized for local feature extraction

↓

Stacked model of two-layers BLSTM network and one-layer ULSTM network is designed to denoise and encode the temporal information

CNN-SBULSTM network-based tool remaining useful life prediction system scheme

(a) Performance comparison

Classical machine learning models

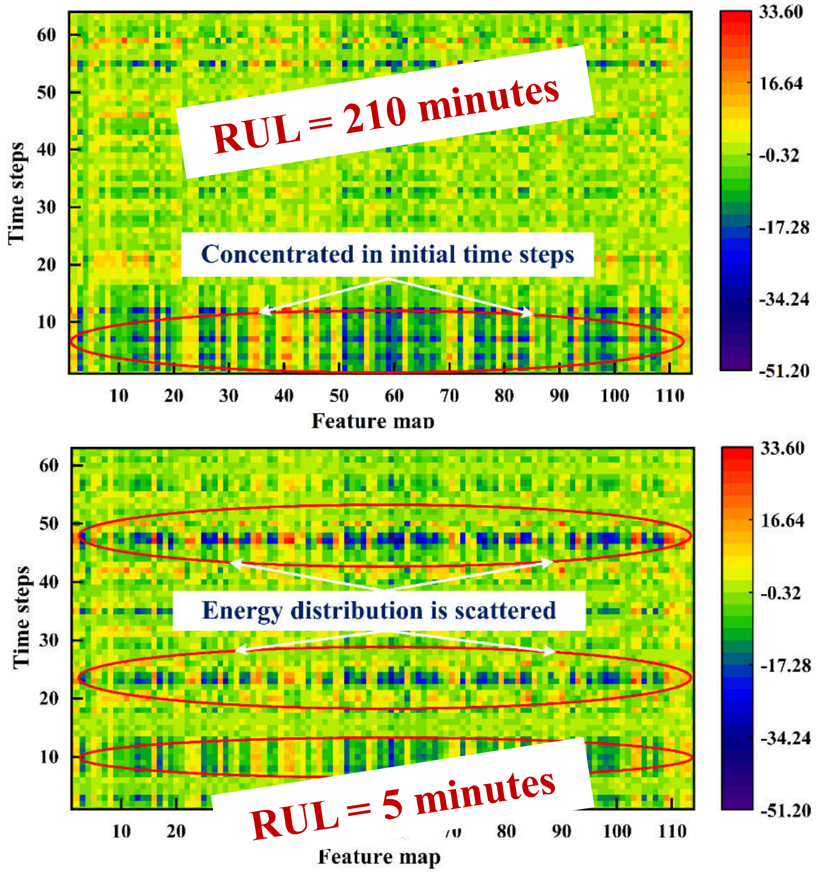
Models	*Score*	*RMSE*	*Accuracy*
SVR	57.5	35.2	0.7
RF	64.03	33.81	0.71
Feed-forward NN	56.5	38.35	0.67
22-layers BLSTM network	87.85	12.26	0.85
6-layers ULSTM network	77.04	23.47	0.75
2-layers CNN	88.42	8.07	0.86
CNN-SBULSTM	88.66	7.81	0.89

Deep learning methods

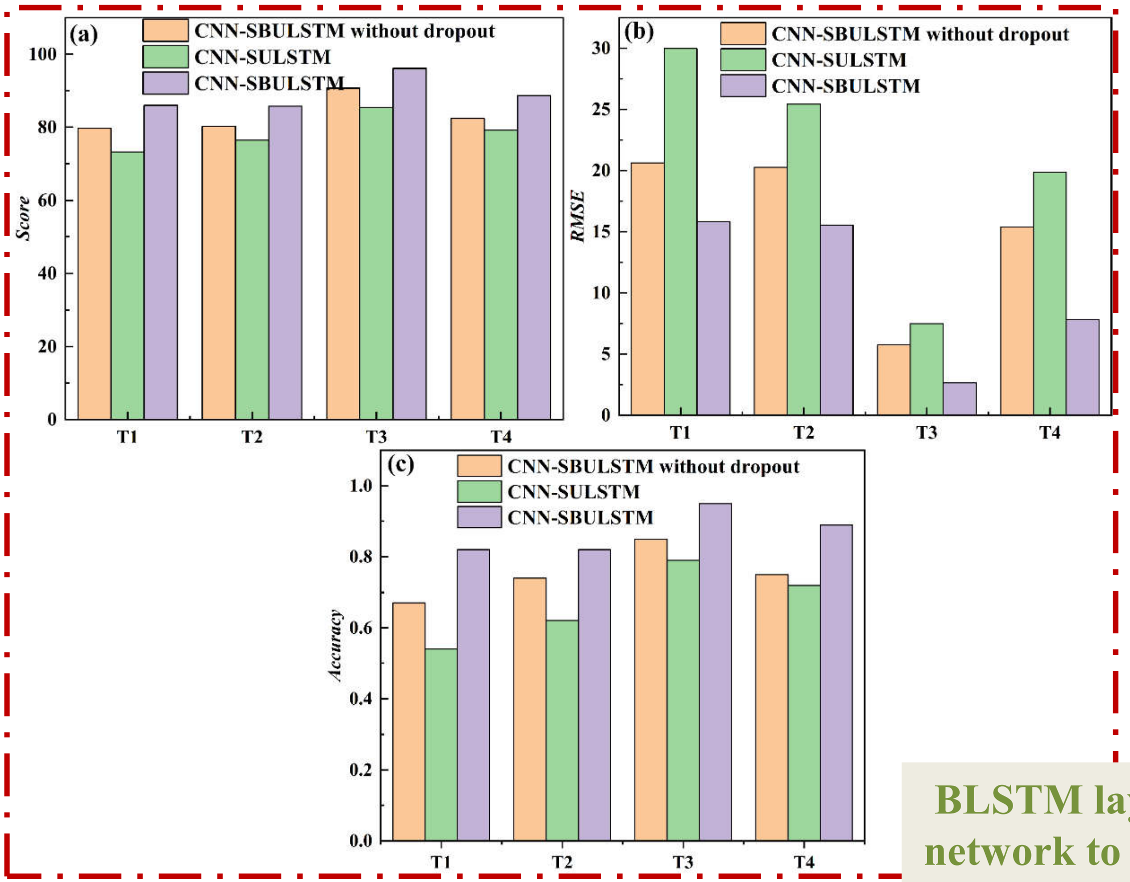
Reasons for performance improvement

1) CNN; 2) Dropout layer; 3) BLSTM layer

(b) CNN extracted features visualization



CNN-SBULSTM network-based tool remaining useful life prediction system scheme



Reasons for performance improvement
2) Dropout layer;3) BLSTM layer

Dropout layer: The dropout layers can relieve possible overfitting

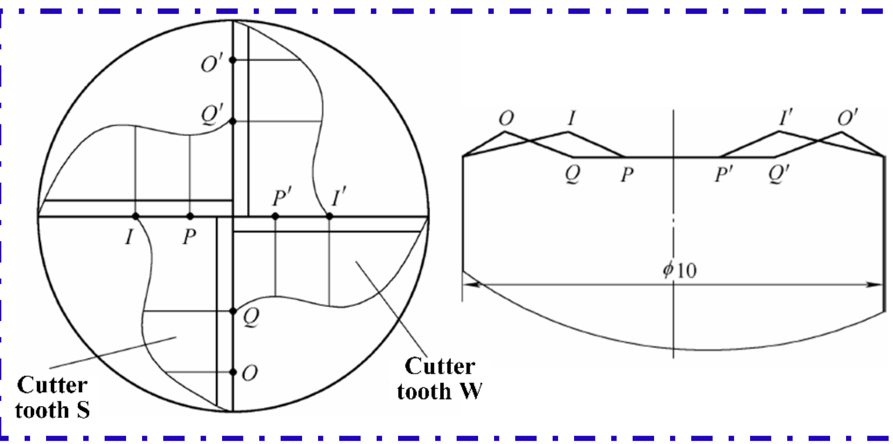
Models	*Score*	*RMSE*	*Accuracy*
CNN-SBULSTM without dropout operation	**82.45**	**15.38**	**0.75**
CNN-SULSTM network	**79.26**	**19.87**	**0.72**
CNN-SBULSTM	**88.66**	**7.81**	**0.89**

BLSTM layer: BLSTM layer enable the SBULSTM network to consider the full context of each time step

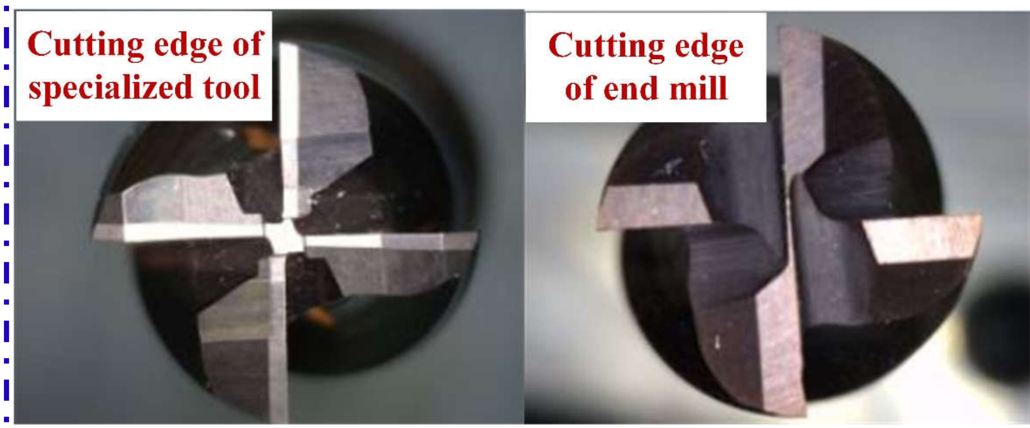
Research on Helical Milling Specialized Tool for CFRP/Titanium alloy

Background: *To machine titanium holes without burr and CFRP holes without delimitation under dry cut condition at aircraft assembly site, a helical milling specialized tool with distributed multi-lattice end cutting edges is designed based on the chip-splitting principle and the movement characteristics of helical milling.*

Key words: Chip-splitting; Helical milling; Multi-point front cutting edge

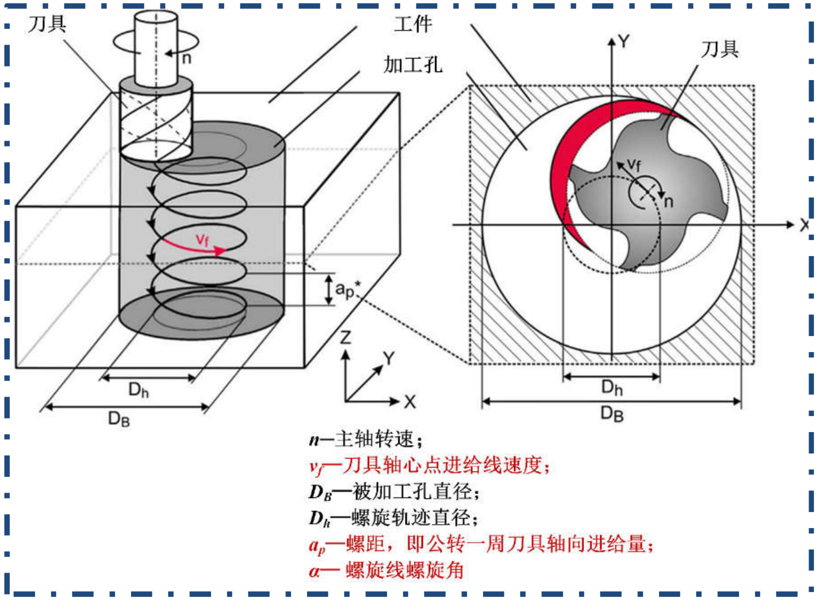


(a) Multi-point front cutting edge

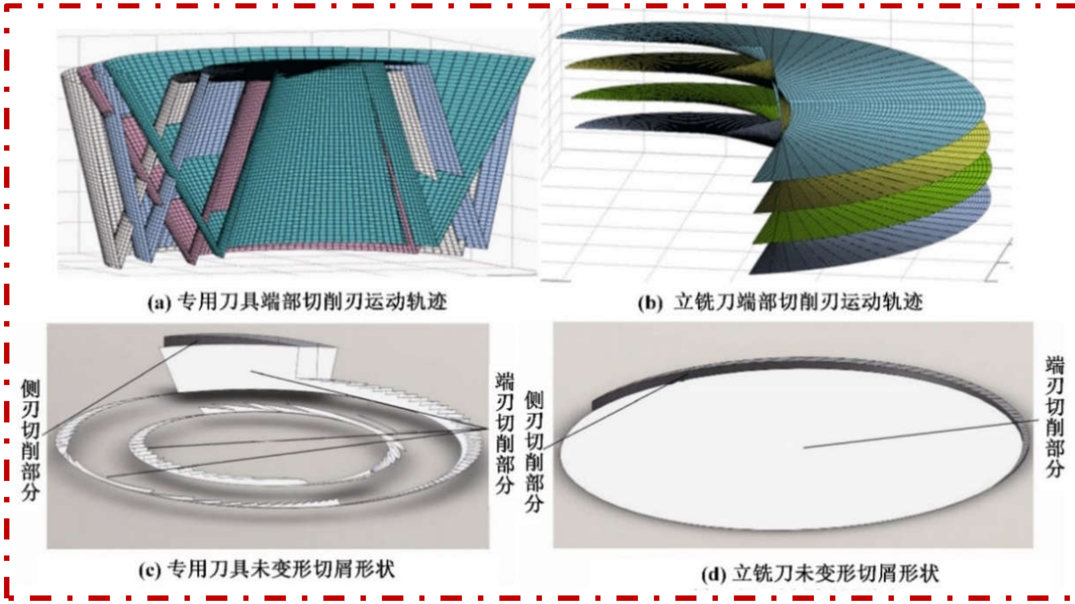


(b) Cutting tool

Chip Separation Simulation



(a) Kinematics analysis

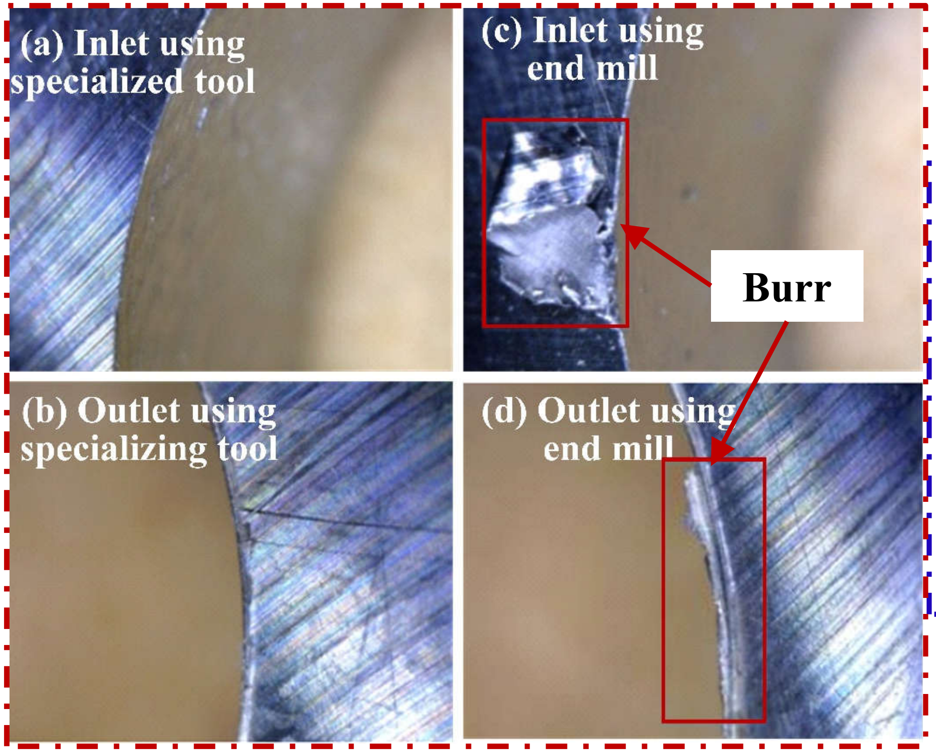


(b) Motion trajectory and undeformed chip simulation

✓ **The superposition of specialized tool end-edge motion path to achieve chip separation**

✓ **The undeformed chip obtained by the end edge of the specialized tool is two rings, and the joint is weak, easy to be separated, and the chip separation effect is good**

Cutting Performance for CFRP/Titanium Alloy

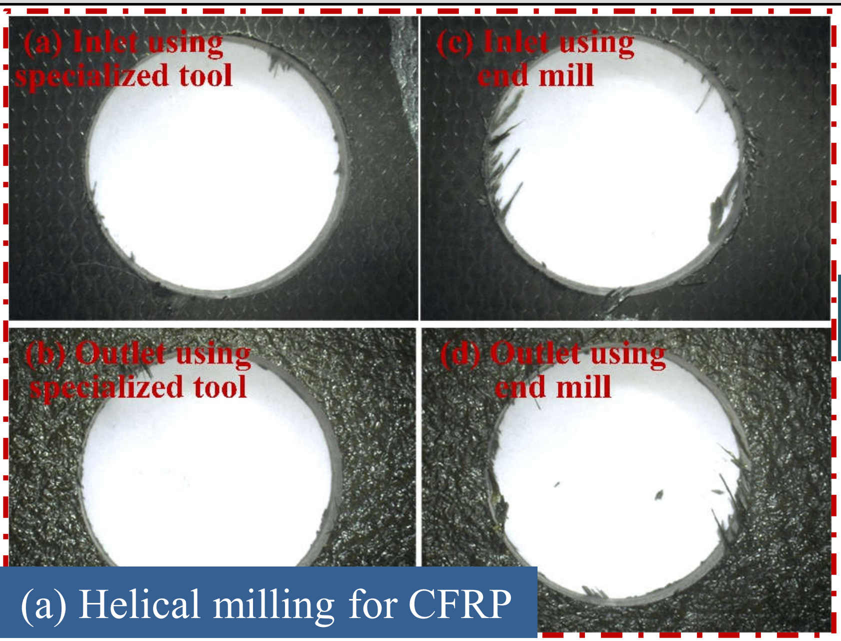


(a) Helical milling for Titanium Alloy

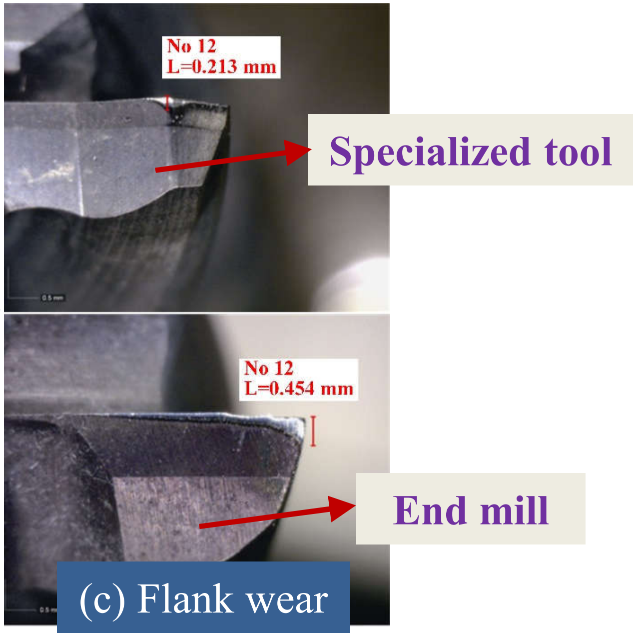
(b) Chip morphology

The hole quality is better than that of the end mill and chips are mostly C-type chips and short band chips

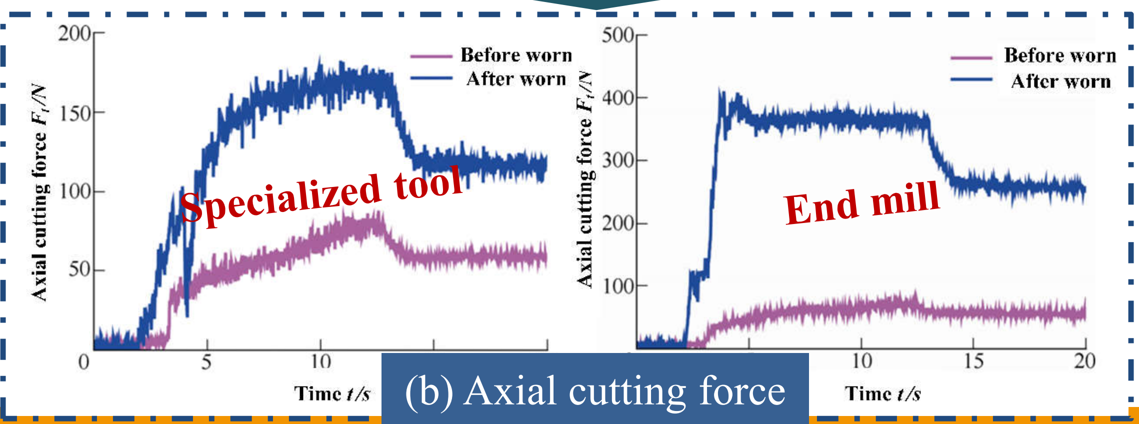
Cutting Performance for CFRP/Titanium Alloy



(a) Helical milling for CFRP



(c) Flank wear



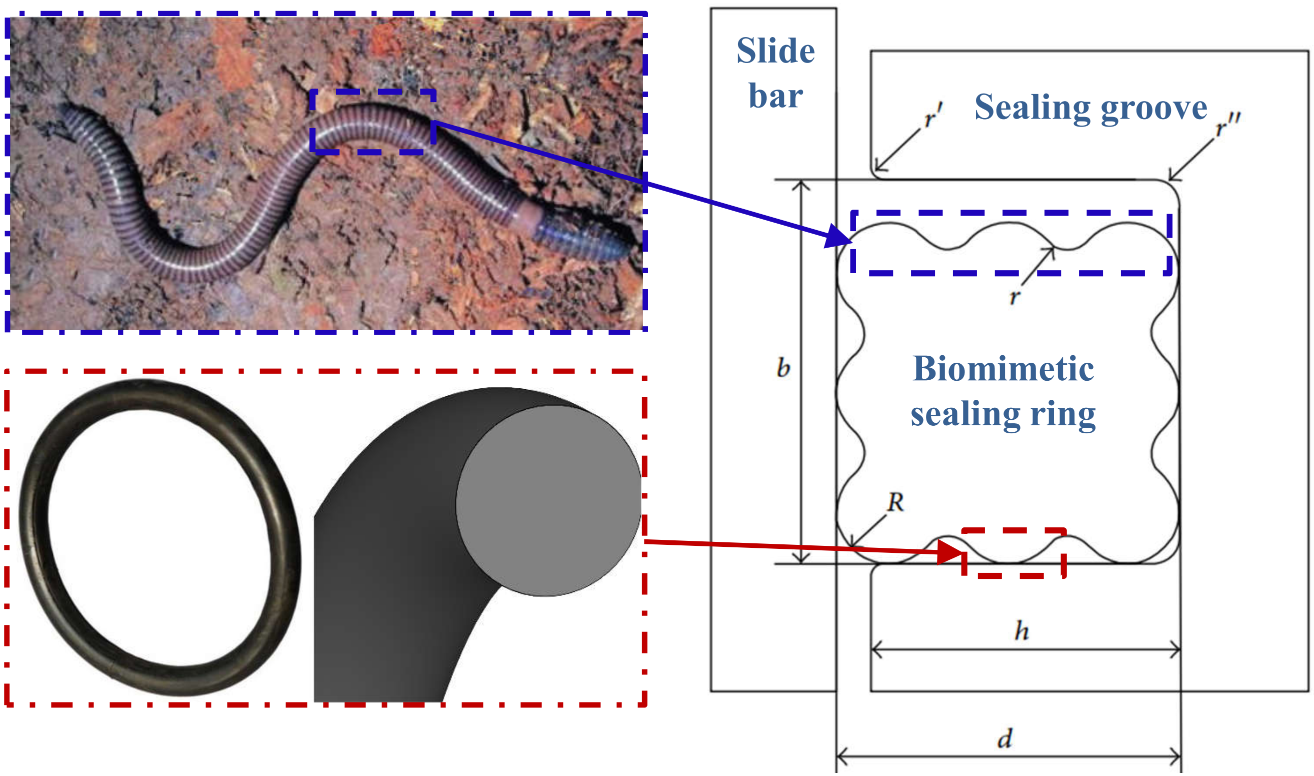
(b) Axial cutting force

After making 12 holes, axial cutting force and flank wear is less than these of end mill, which means much longer service life

Structural Design and Sealing Performance Analysis of Biomimetic Flexible Sealing Ring

Background: *In order to reduce the failure probability of rubber sealing rings in reciprocating dynamic seal, a new structure of sealing ring based on bionics was designed.*

Key words: Bioinspired structure design; Rubber seal; Finite element method



Finite Element Analysis

(a) Material Constitutive of Rubber: Mooney-Rivlin model

$$W = C_1\left(I_1 - 3\right) + C_2\left(I_2 - 3\right)$$

$$\sigma = \frac{\partial W}{\partial \varepsilon}$$

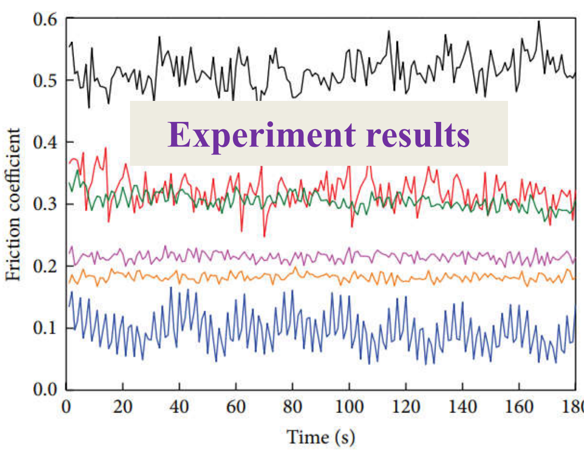
(c) Loading and Boundary Conditions

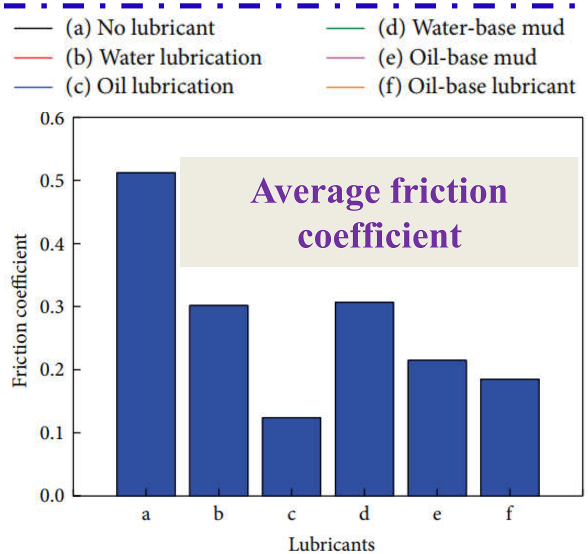
✓**Step 1:** precompression (0.3 mm) to simulate the installation

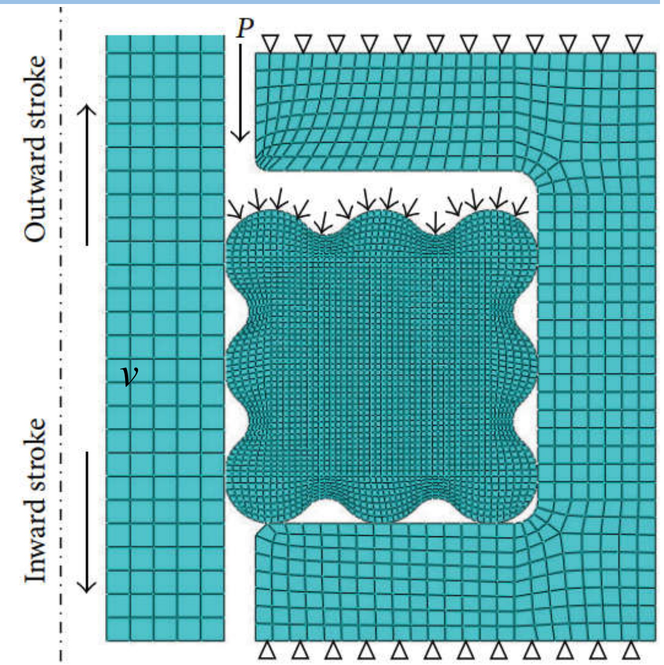
✓**Step 2:** medium pressure (P = 3 Mpa) was loaded on the working surface

✓**Step 3:** apply the axial velocity (***v***= 0.2 m/s) at slide bar

(b) Friction Coefficients



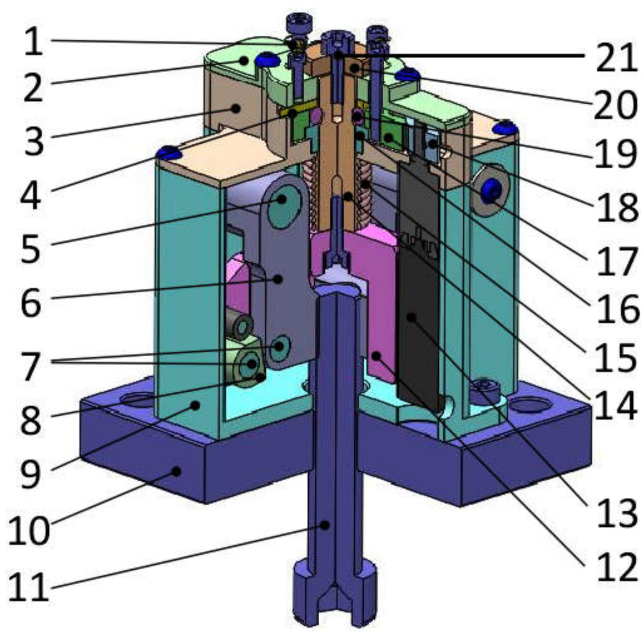


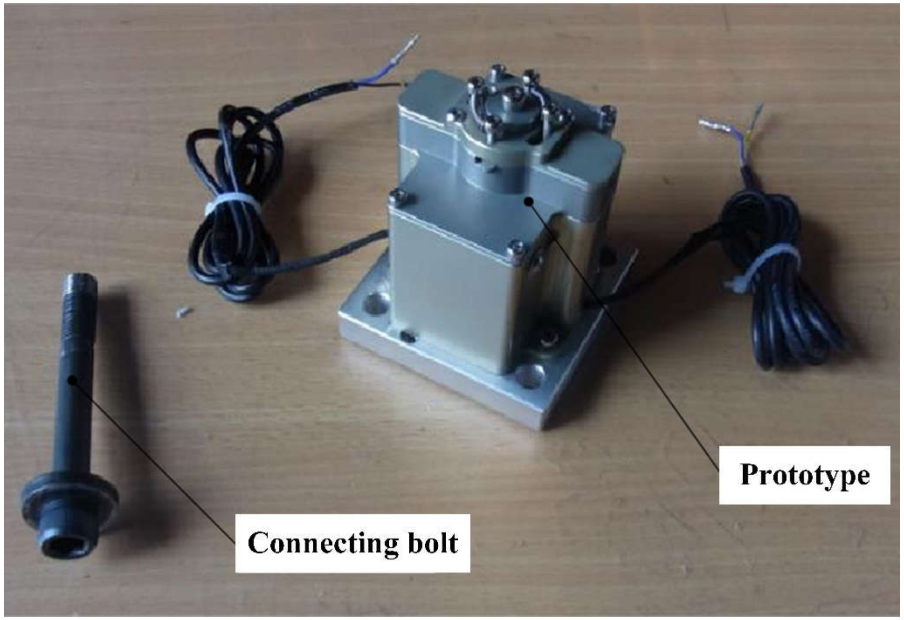


Research and Development of Low-Shock and Non-Explosive Separation Device

Background: De*velop a low-shock non-explosive separation device that would connect the launch vehicle and small satellite reliably, and release the locking constraint when receiving separation signal.*

Key words: Separation device; Low shock; Segmented nut

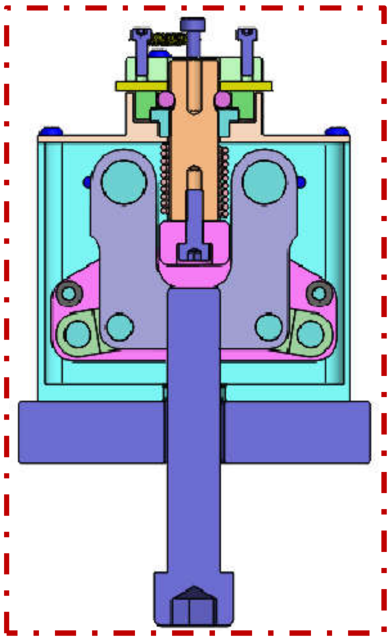




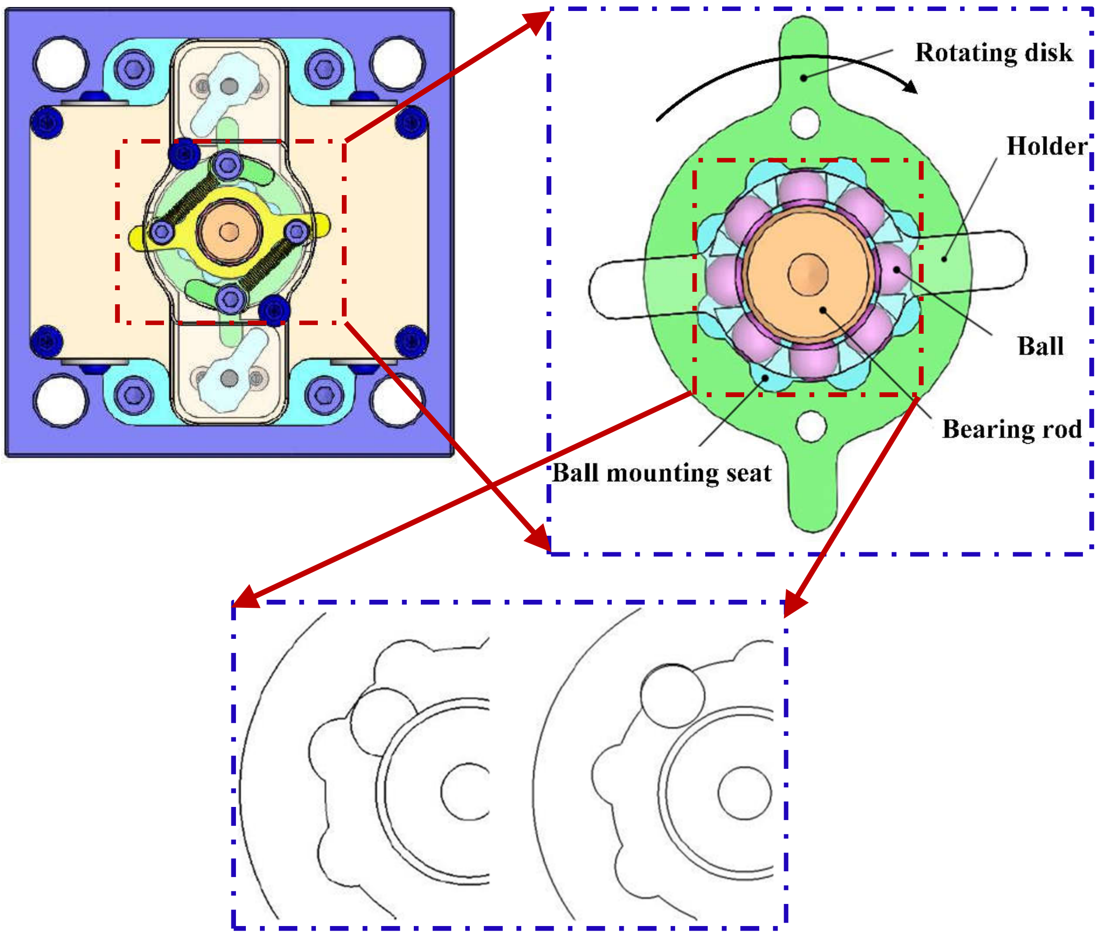
1. Reset spring; 4. Holder; 6. Release clamp; 10. Base; 11. Connecting Bolt; 13. DC motor; 14. Bearing rod 15. Release spring; 19. Ball; 21. Reset Bolt

Working Mechanism

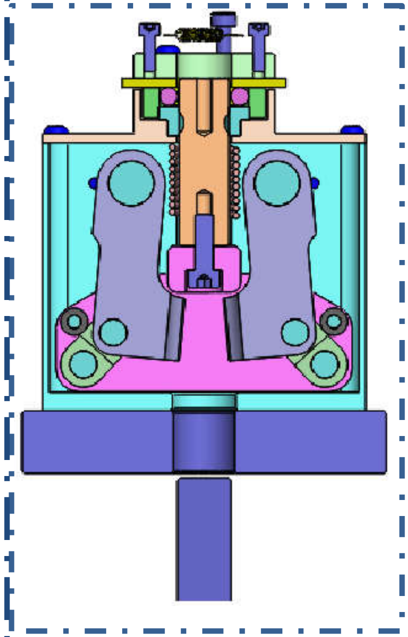
(a) Locked



(b) Releasing process



(c) Released



III. Publications & Presentations

Publications in the Fields of Manufacturing Technology and Data-driving Model

1. **Z. Tao**, Q. An, G. Liu, M. Chen. A Novel Method for Tool Condition Monitoring Based on Long Short-Term Memory and Hidden Markov Model Hybrid Framework in High-Speed Milling Ti-6Al-4V. ***International Journal of Advanced Manufacturing Technology***, 105 (2019) 3165-3182. (***Published, IF=2.496***)
2. **Z. Tao,** J. Dang, J. Xu, Q. An, M. Chen, L. Wang, F. Ren. Eddy Current Distance Measurement Calibration Method for Curved Surface Parts Based on Support Vector Machine Regression. ***Journal of Shanghai Jiaotong University*** in Chinese with English abstract, 2019. (***Accepted, IF=0.955***)
3. **Z. Tao**, J. Dang, J. Xu, Q. An, F. Ren, L. Wang. High-precision calibration method and application for coating thickness measurement of curved surface based on eddy current displacement sensor. ***Journal of Zhejiang University (Engineering Science)*** in Chinese with English abstract, 2019. (***Accepted, IF=1.018***)
4. Q. An, J. Chen, **Z. Tao**. Experimental investigation on tool wear characteristics of PVD and CVD coatings during face milling of Ti-6242S and Ti-555 titanium alloys. ***International Journal of Refractory Metals and Hard Materials***, 86 (2020) 105091. (***Published, IF=2.794***)
5. Q. An&, **Z. Tao**&, X. Xu, M. El Mansori (&co-first authors). "A Data-driven Model for Milling Tool Remaining Useful Life Prediction with Convolutional and Stacked LSTM Network." ***Measurement***, (2019) 107461. (***Online, IF=2.791***)
6. C. Cai, X. Liang, Q. An, **Z. Tao**. "Experimental Study *Under*on the Cooling/Lubrication Performance of Dry and Supercritical CO_2-based Minimum Quantity Lubrication in Peripheral Milling Ti-6Al-4V." ***International Journal of Precision Engineering and Manufacturing-Green Technology***, 2019. (***Accepted***)
7. J. Li, **Z. Tao**. Experimental and Finite Element Analysis of the Formation Mechanism of Serrated Chips of Nickel-based Superalloy Inconel 718. ***International Journal of Advanced Manufacturing Technology***, 2019 (*Under Review*)
8. X. Xu, **Z. Tao**, Q. An, M. Chen. "A Multimodal Based on Deep Learning and Multi-sensor Information Fusion for Monitoring and Diagnostics." ***Measurement***, 2019. (Under *Review*)

Two Conference Papers and One China Patent

1. **<u>Z. Tao</u>**, Q. An, M. Chen. Cutting Performance Evaluation of Helical Milling Specialized Tool for CFRP/Titanium Alloy. ***14th China-Japan International Conference on Ultra-Precision Machining Process***, Harbin, Sept 13-15, 2018 (***Best Paper***).
2. **<u>Z. Tao</u>**, G. Liu, Q. An, M. Chen. Hierarchical Dirichlet Process Hidden Semi-Markov Model-based Method for Tool Wear Estimation in High-Speed Milling Ti-6Al-4V. ***8th International Conference on High Speed Machining***, Guangzhou, Nov 22-24, 2018 (***Excellent Poster***)
3. M. Chen, F. Ren, **<u>Z. Tao</u>**. "Non-contact Type Measuring Method and Device for Metal Surface Coating Thickness." China Patent, CN109141325A (*In Public*);

IV. Other Activities

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Volunteer - The First International Import Expo / 2018 Shanghai International Marathon / 2018 WAIC (World Artificial Intelligence Conference)

编号（Number）：0146

WAIC
2018世界人工智能大会
WORLD ARTIFICIAL INTELLIGENCE CONFERENCE

志愿者服务证书
VOLUNTEER CERTIFICATE

陶正瑞 同学：

感谢你参与2018年9月17--9月23日举办的2018世界人工智能大会志愿者服务工作，大会期间认真负责、团结协作、勇于奉献，表现优异。

特颁此证，以资鼓励！

This certificate is presented for your outstanding volunteer work in the 2018 WAIC (World Artificial Intelligence Conference) that was hosted in Shanghai from 17th September to 23rd September 2018. It also serves as a special award for your responsibility, solidarity, cooperation and dedication.

2018世界人工智能大会组委会
共青团上海市徐汇区委员会(代章)
2018年9月

2018 上海国际马拉松赛 SHANGHAI INTERNATIONAL MARATHON
上海青年志愿者

志愿者服务证书
CERTIFICATE FOR VOLUNTEERS

亲爱的志愿者 陶正瑞 ：

2018 上海国际马拉松赛于 11 月 18 日在上海举行。
您作为此次赛事志愿者提供了志愿服务。
衷心感谢您为本项赛事作出的杰出贡献。

Dear Tao Zhengrui :

This is to certify your excellent services as a volunteer for the 2018 Shanghai International Marathon, which were held in Shanghai on Nov.18th.
Thank you for your hard work.

上海国际马拉松赛组委会
Organizing Committee of Shanghai International Marathon

上海市青年志愿者行动指导中心
Shanghai Young Volunteers Guidance Center

SHANGMA VOLUNTEER

新时代，共享未来
New Era, Shared Future

编号(Number)
05907

首届中国国际进口博览会志愿者服务证书
Volunteer Service Certificate of the First China International Import Expo

尊敬的 陶正瑞 先生/女士：

首届中国国际进口博览会于2018年11月5日-11月10日在中国上海举行。感谢您作为志愿者(储备)，为首届中国国际进口博览会的筹备和举办作出的贡献。

特颁此证，以资纪念！

Dear Mr/Ms Tao Zhengrui

The First China International Import Expo was held in Shanghai from November 5th to 10th, 2018. Thank you for service and contribution to the First China International Import Expo as a volunteer (reserve).

首届中国国际进口博览会执行委员会主任
Director, the Organizing Committee of the First China International Import Expo
商务部部长
Minister of Commerce

首届中国国际进口博览会执行委员会主任
Director, the Organizing Committee of the First China International Import Expo
上海市人民政府市长
Mayor of Shanghai

首届中国国际进口博览会执行委员会
The Organizing Committee of the First China International Import Expo
2018年11月
November, 2018

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Internship – Data analyst at the Engine Systems Dept. of FCA company; Software developer at the Clobotics

Teaching Assistant - Course: *Introduction to Engineering*

Thank you!