Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Investigation of high-speed rubbing behavior of labyrinth-honeycomb seal for turbine engine

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Cite this as: Na ZHANG, Hai-jun XUAN, Xiao-jun GUO, Chao-peng GUAN, Wei-rong HONG, 2016. Investigation of high-speed rubbing behavior of labyrinth-honeycomb seal for turbine engine application. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 17(12):947-960. http://dx.doi.org/10.1631/jzus.A1600367

Materials & Methods

Test equipment

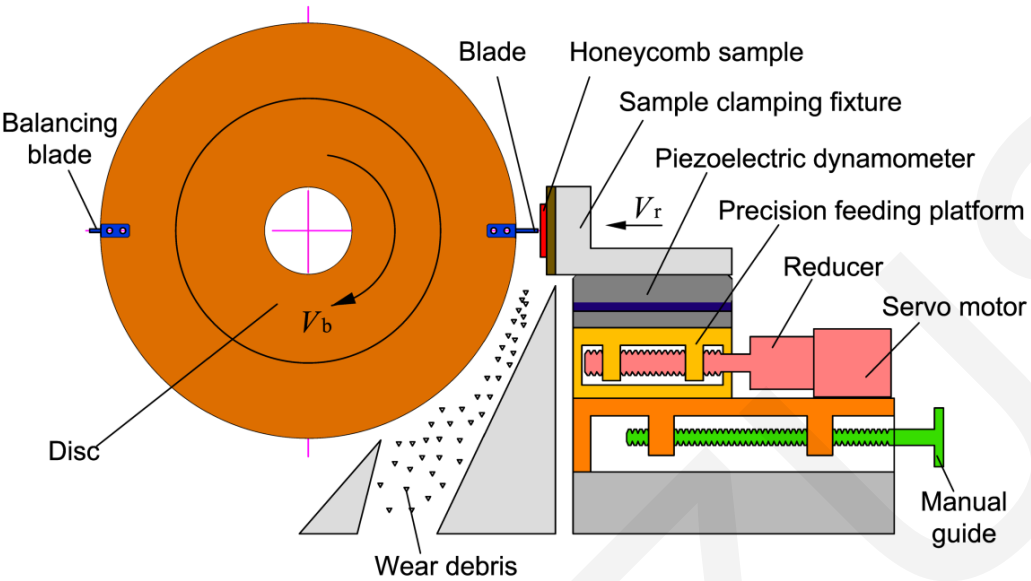
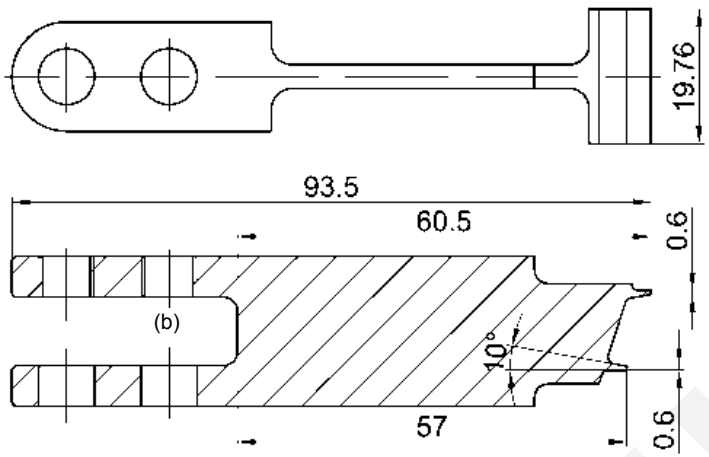


Fig. 1 Test schematic diagram (left) and general view of abradable test rig (right)

- The maximum rotating speed: 16000 r/min;
- The maximum blade tip velocity: 520 m/s;
- Incursion rate of the feeding system: from 5 to 1000 μm/s;
- Control precision of the feeding system: 3 μm/s;

Materials & Methods

■ Test materials



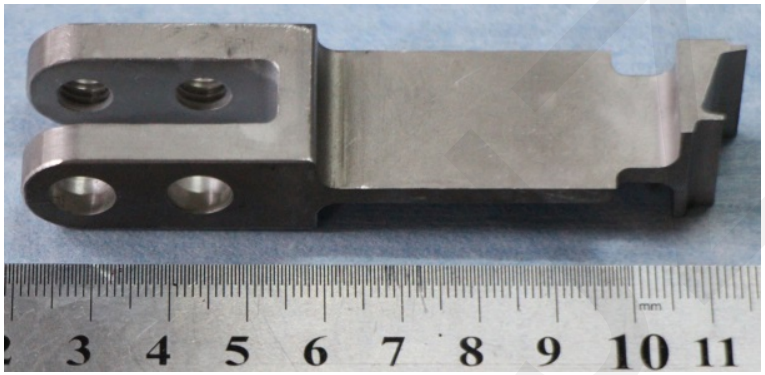


Fig.2 Schematic of simulated blade and its photo.

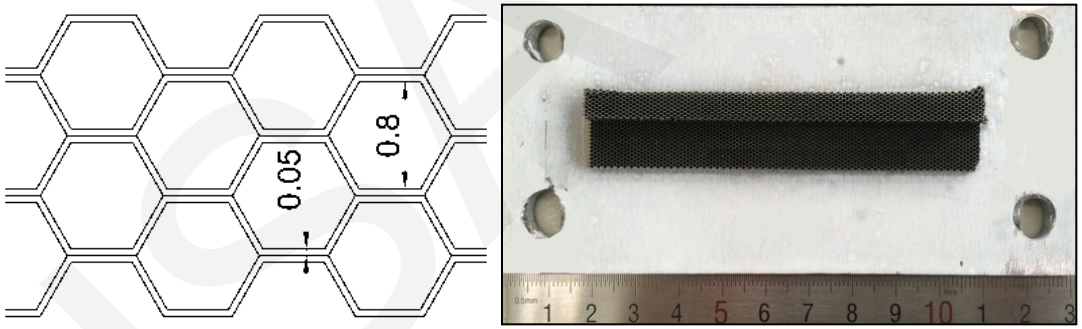


Fig. 5 Honeycomb sample used in rubbing test

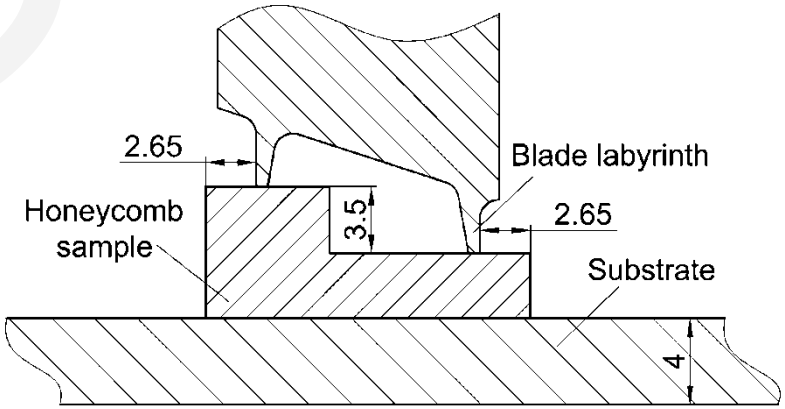


Fig.6 Location diagram of honeycomb sample and blade labyrinth.

Materials & Methods

■ Test scheme

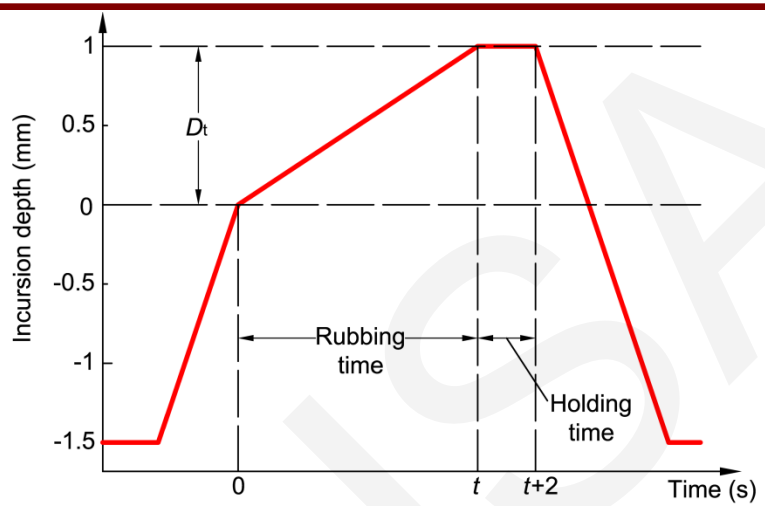


Fig.7 Typical incursion process during rubbing test.

Table 1 Test parameters used in this work.

Test No.	Blade tip speed, V_b (m/s)	Incursion rate, V_r (μm/s)	Incursion depth per pass, D_p (μm)	Incursion depth, D_t (μm)	Holding time, T_r (s)
1#	150	120	1.558		
2#	150	240	3.117		
3#	150	360	4.675		
4#	300	120	0.779		
5#	300	240	1.558	1000	2
6#	300	360	2.338		
7#	450	120	0.519		
8#	450	240	1.039		
9#	450	360	1.558		

Materials & Methods

■ Rubbing forces and acceleration measurements

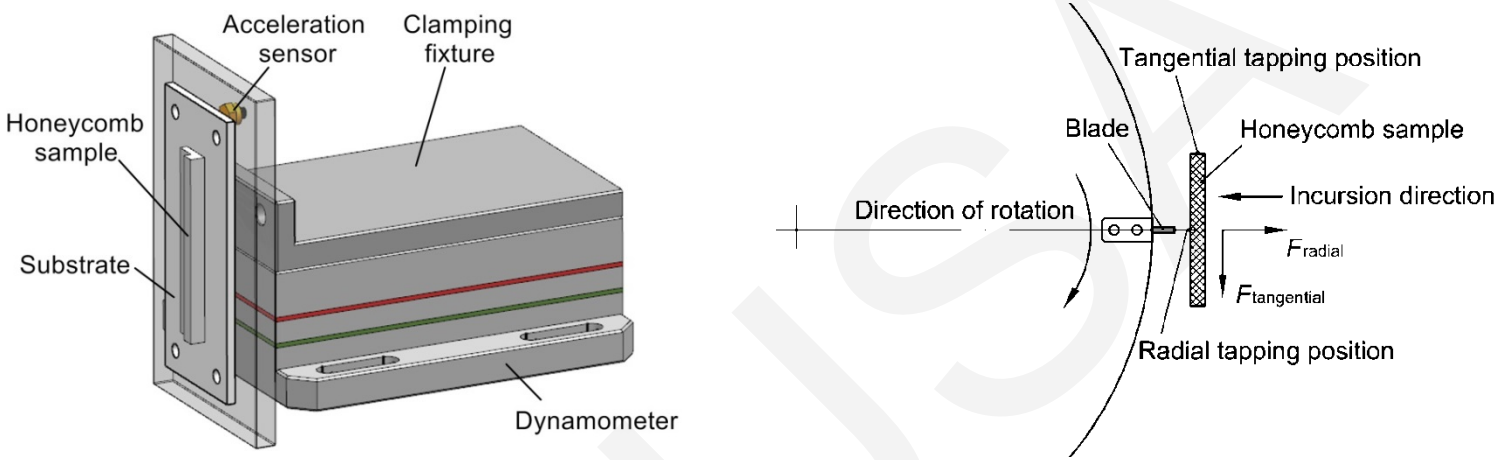


Fig. 8 Experimental device used to measure the rubbing force and impact acceleration .

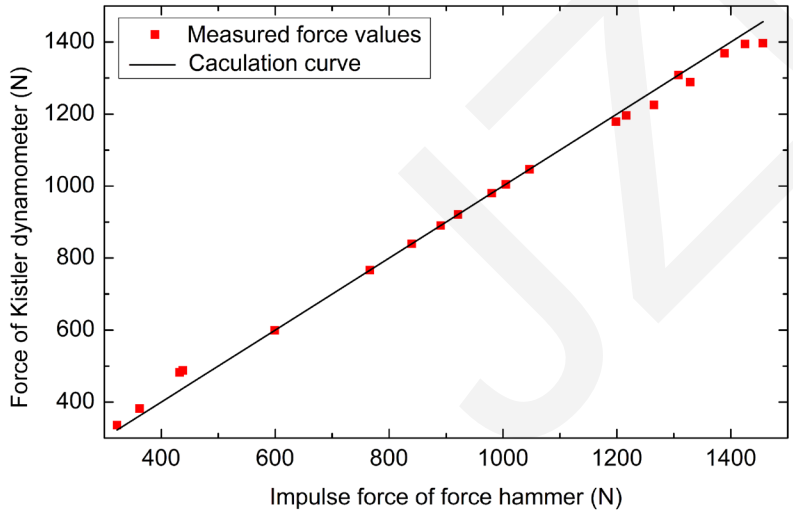


Fig. 9 Calibration curve of dynamometer signal.

- Rubbing forces: Kistler 9257B, ±5000 N
- Acceleration: PCB 352C41, ±500*g*
- High-speed data acquisition system: GEN3i with a GN815 data acquisition card.

- Caculation curve shows that it is appropriate for the Kistler dynamometer to measure the rubbing force.

Test results and discussion

Analysis of test samples

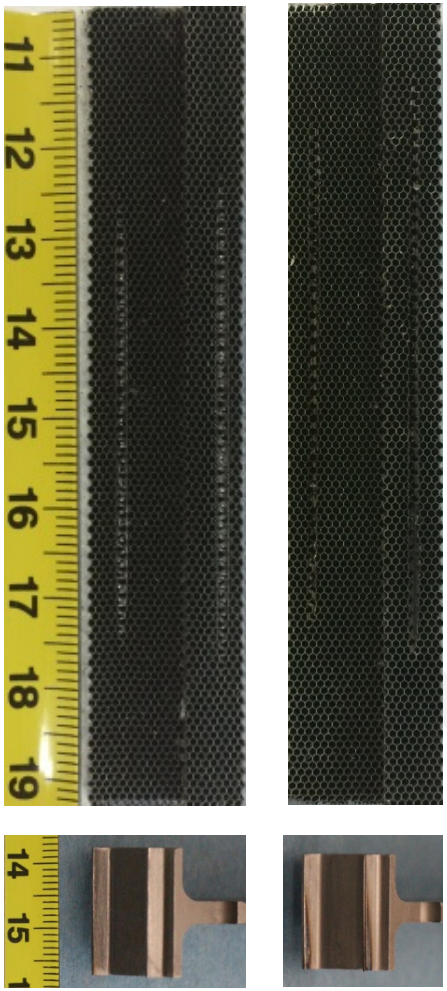


Fig.10 Test results of 1# and 7#.

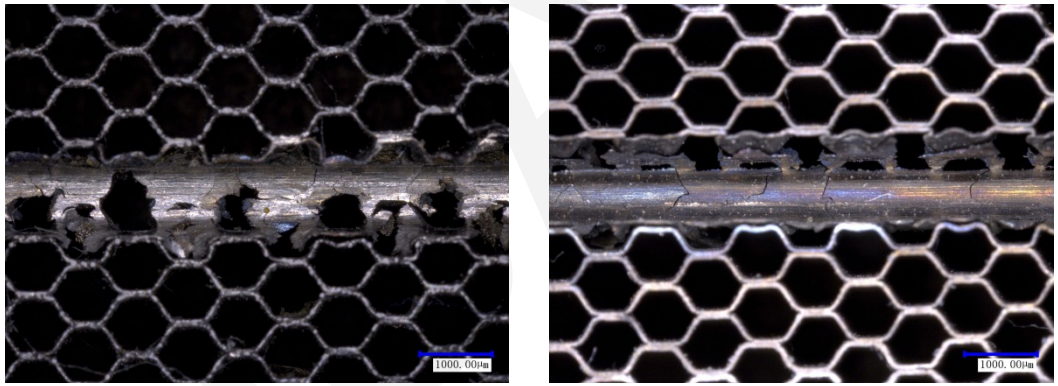
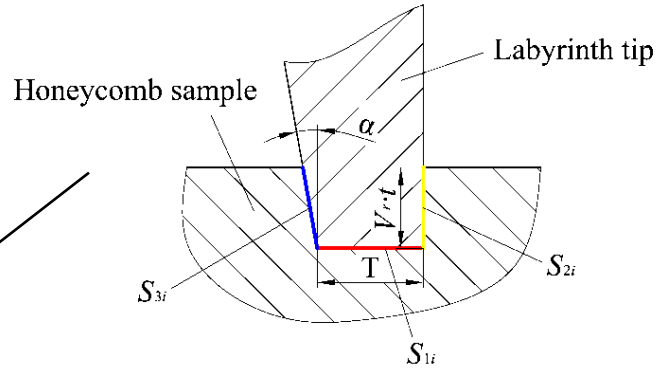


Fig.11 Details of blocked honeycomb for test 6# and 7#.

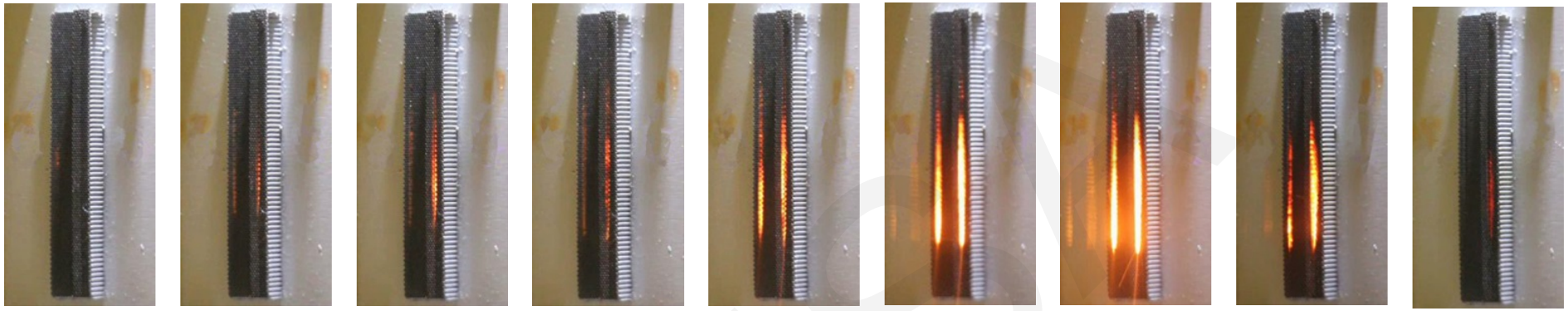


The total scraping area:

$$S(t) = \sum_{i=1}^{2}\left(S_{1i} + S_{2i} + S_{3i}\right)$$

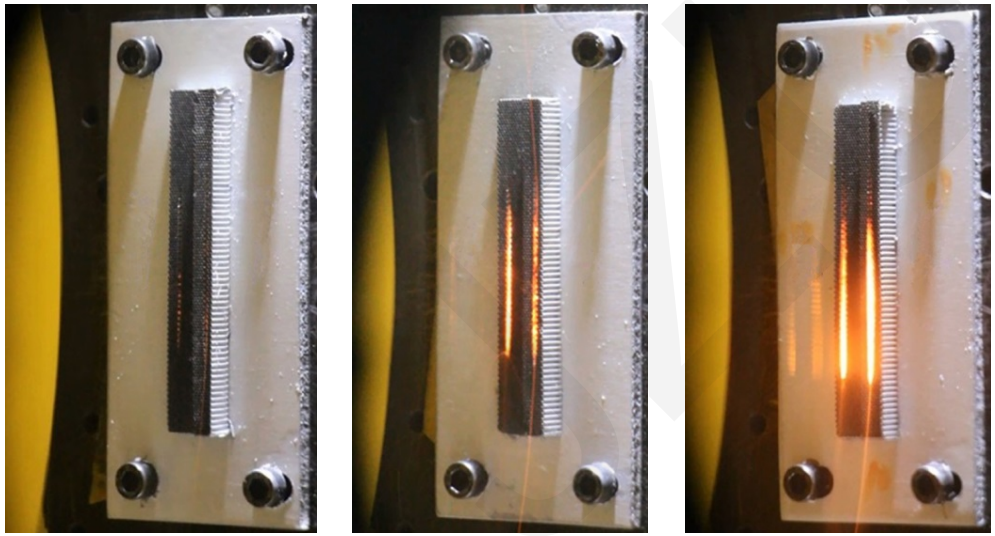
$$= \sum_{i=1}^{2}\left[\begin{array}{l} R_i\left(2R_i + T + \frac{R_i}{\cos\alpha}\right) \times \arccos\left(1 - \frac{V_r t}{R_i}\right) \\ -\left(1 + \frac{1}{\cos\alpha}\right)\left(R_i - V_r t\right) \times \sqrt{2V_r t \cdot \left(R_i - V_r t\right)} \end{array}\right]$$

Test results and discussion



(a) t=0 s (b) t=2 s (c) t=4 s (d) t=6 s (e) t=8 s (f) t=10 s (g) t=12 s (h) t=14 s (i) t=16 s

Fig.13 Video recording of one rubbing process. (V_b= 450 m/s, V_r= 120 μm/s)



(a) V_b= 150 m/s (b) V_b= 300 m/s (c) V_b= 450 m/s

Fig.14 Friction sparks different rubbing tests.

- The wear mechanisms of metal honeycomb:
  Cutting, oxidation, compression deformation, smearing, adhesive transfer.
- The mechanisms of turbine blade:
  Wear, thermal ablation and oxidation.

Test results and discussion

Analysis of rubbing forces and accelerations

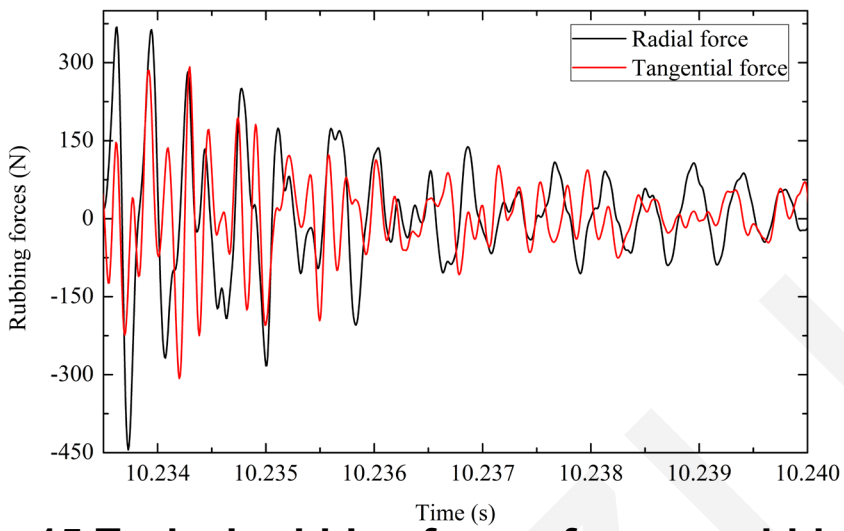


Fig.15 Typical rubbing forces for one rubbing cycle. (V_b= 300 m/s, V_r= 120 μm/s)

- An attenuation response will be generated when the rubbing force is input because of a mass-spring-damper system.
- Each force curve is composed of four stages: pre-rubbing, rubbing, holding and termination stage.

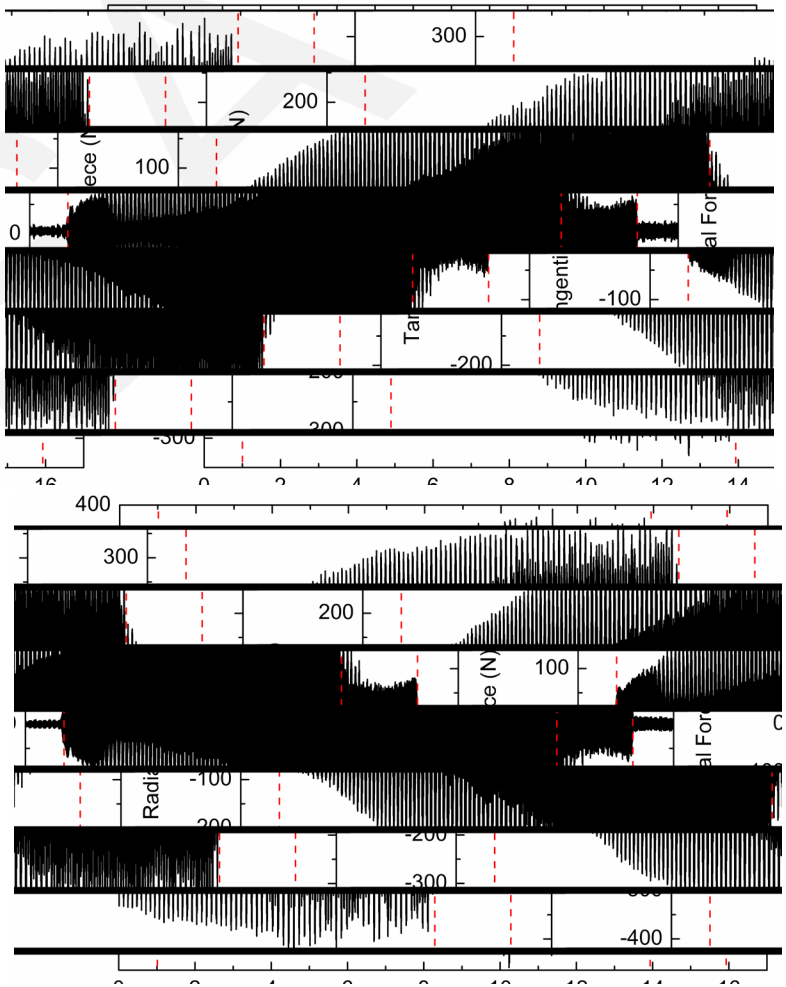


Fig.16 Tangential and radial forces recorded over the rubbing period.

Test results and discussion

Analysis of rubbing forces and accelerations

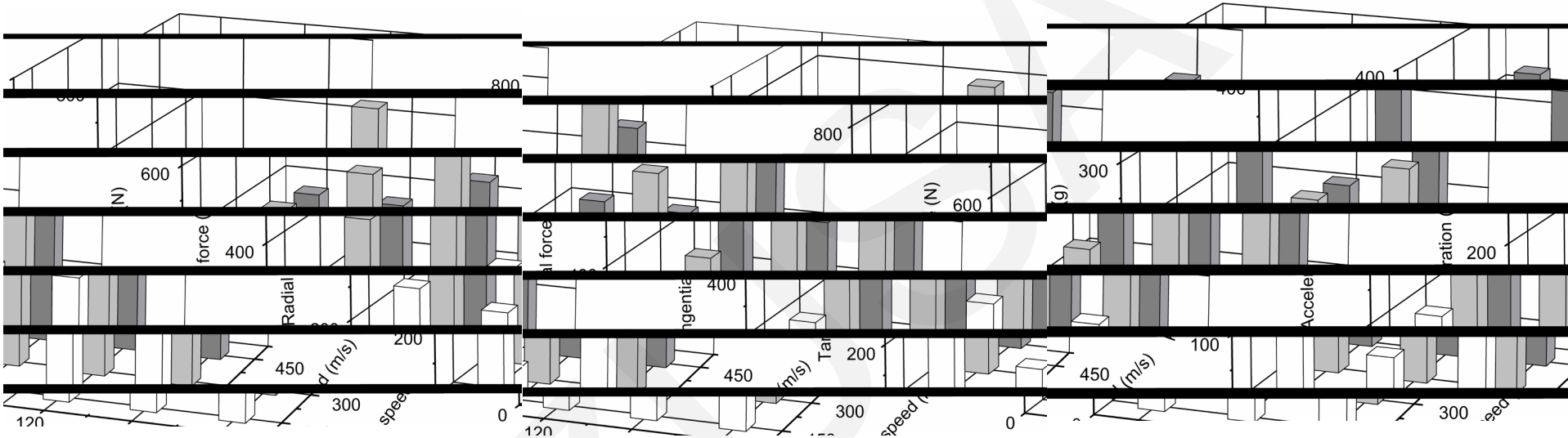


Fig.17 Maximum values of radial, tangential forces and acceleration for nine tests.

- The maximum forces in radial and tangential directions are 716 N and 871 N respectively under the condition of 300 m/s blade tip speed and 360 μm/s incursion rate, and neither would cause damage to the rotating blade labyrinth.
- The highest acceleration value is 341 g under the highest blade tip speed of 450 m/s and the highest incursion rate of 360 μm/s.

Conclusions

- Compression deformation occurs on the honeycomb material during the rubbing process except for the cutting mechanism.
- Thermal ablation, oxidation and smearing occur on the turbine blade, and the friction heat can cause the adhesive transfer of honeycomb material to the labyrinth tips.
- With a blade tip speed of 300 m/s and incursion rate of 360 μm/s, radial and tangential forces show their maximum values of 716 N and 871 N, respectively, and neither of them could cause damage to the rotating rotor.
- The peak value of acceleration presents 341*g* in the test with the highest blade tip speed of 450 m/s and the highest incursion rate of 360 μm/s.