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

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Materials & Methods

Test equipment

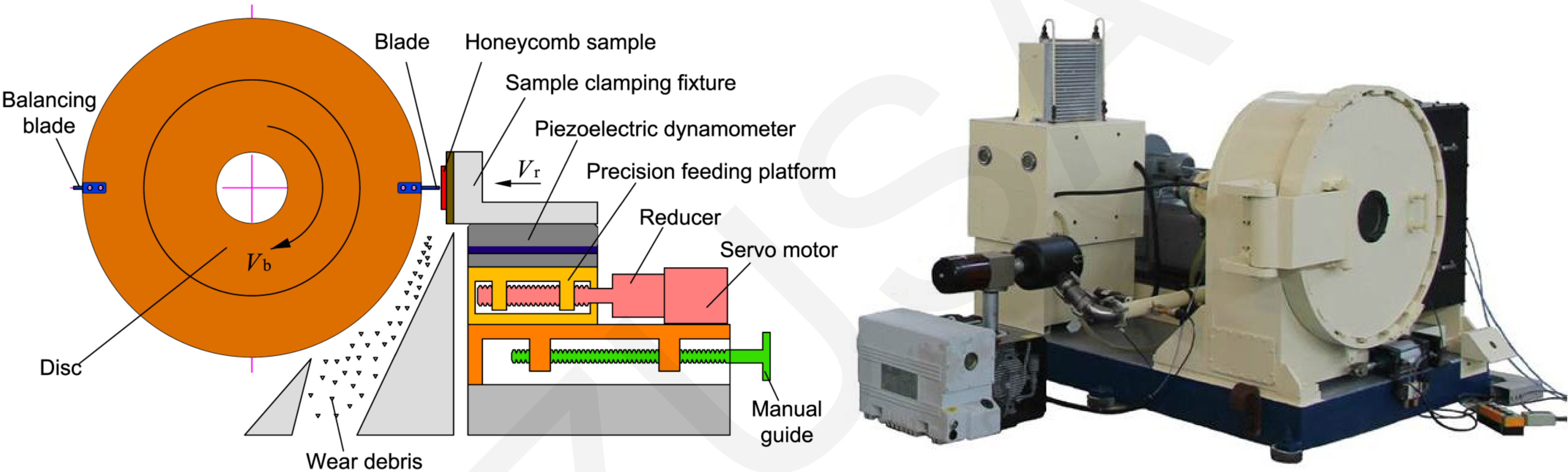


Fig. 1 Test schematic diagram (left) and general view of abradable test rig (right)

- 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

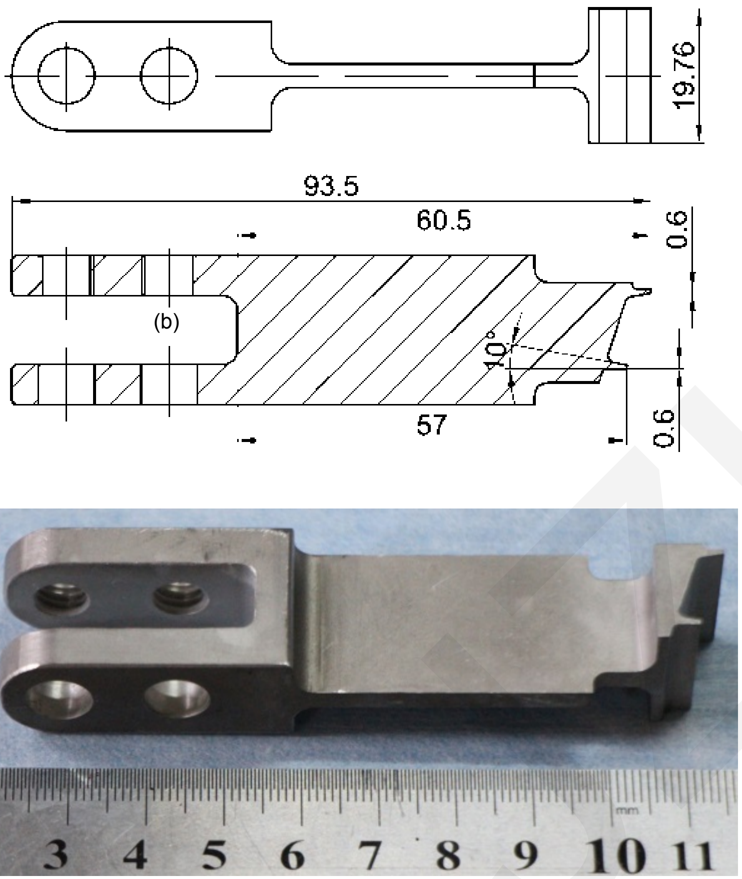


Fig.2 Schematic of simulated blade and its photo.

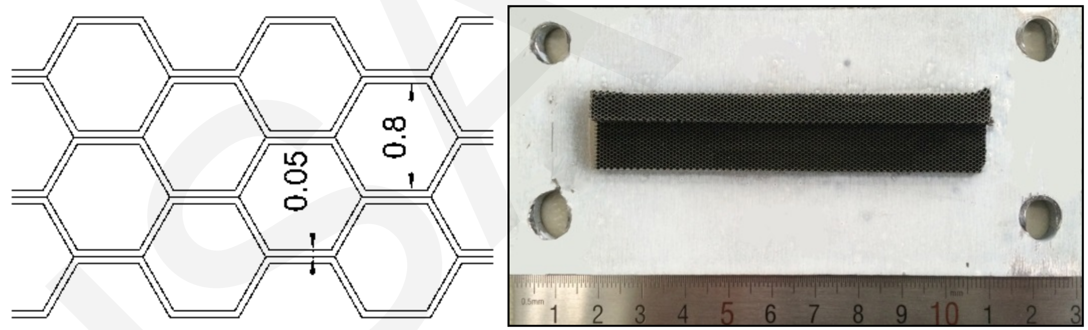


Fig. 5 Honeycomb sample used in rubbing test

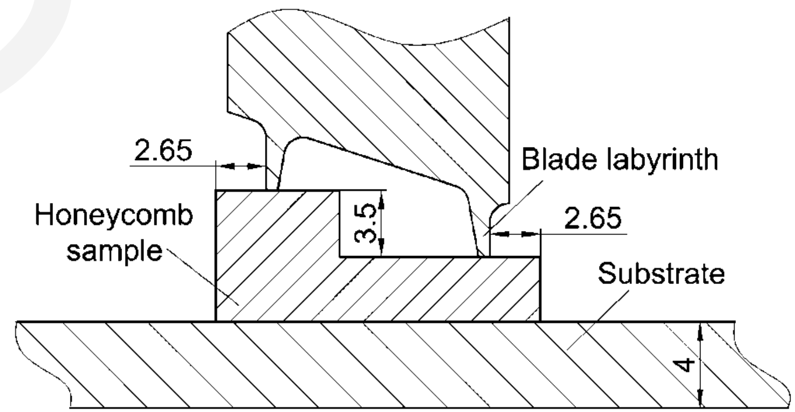


Fig.6 Location diagram of honeycomb sample and blade labyrinth.

Materials & Methods

■ Test scheme

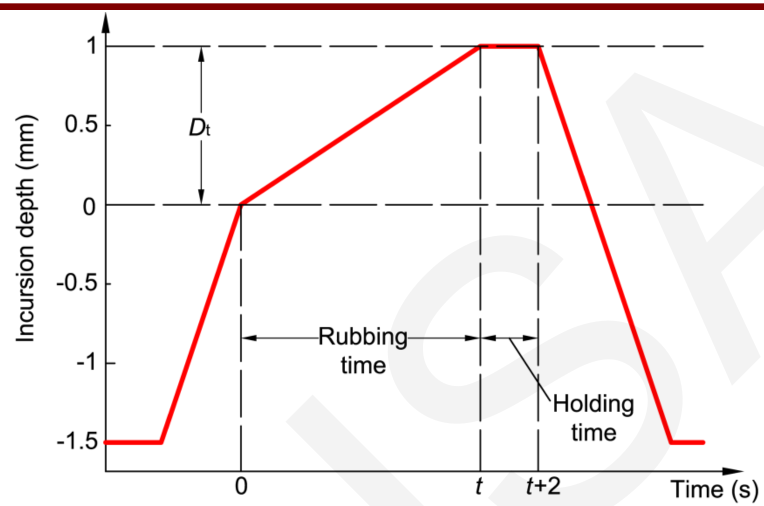


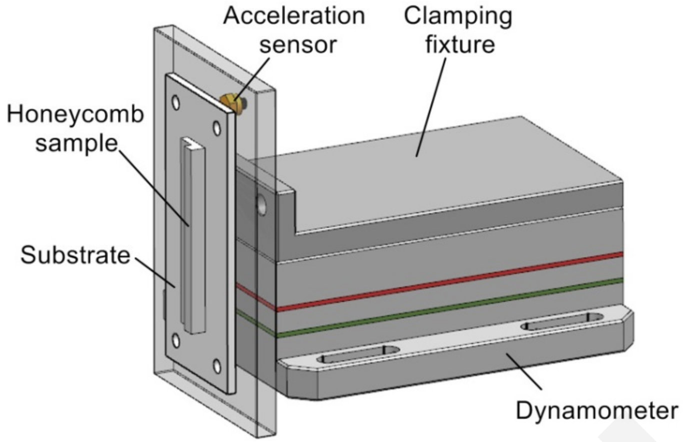
Fig.7 Typical incursion process during rubbing test.

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



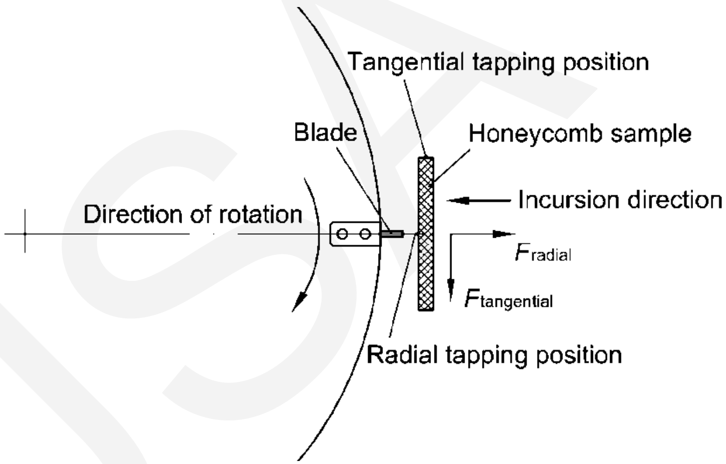


Fig. 8 Experimental device used to measure the rubbing force and impact acceleration .

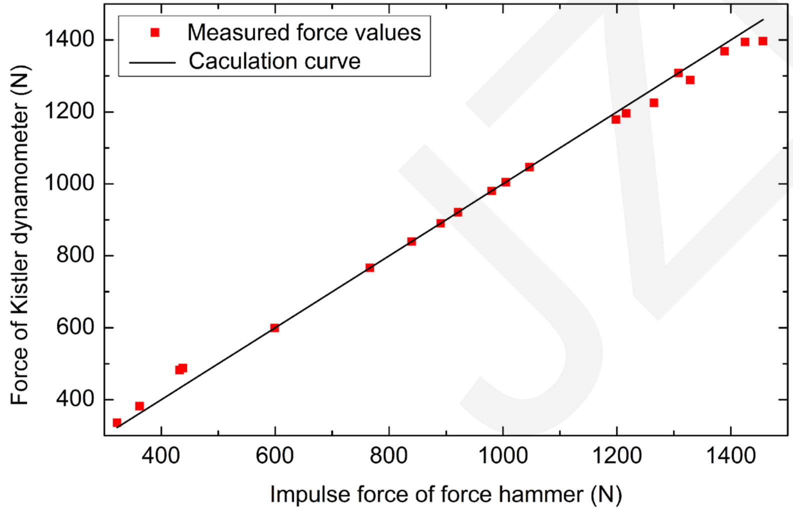


Fig. 9 Calibration curve of dynamometer signal.

- 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

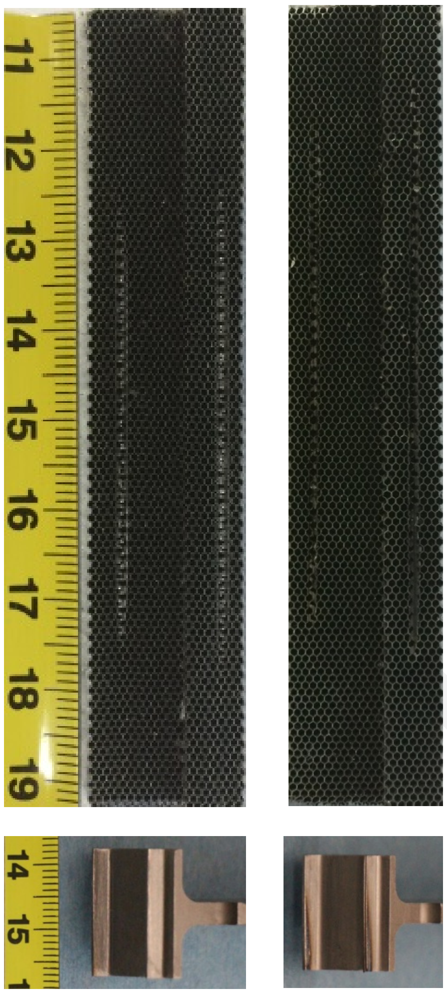


Fig.10 Test results of 1# and 7#.

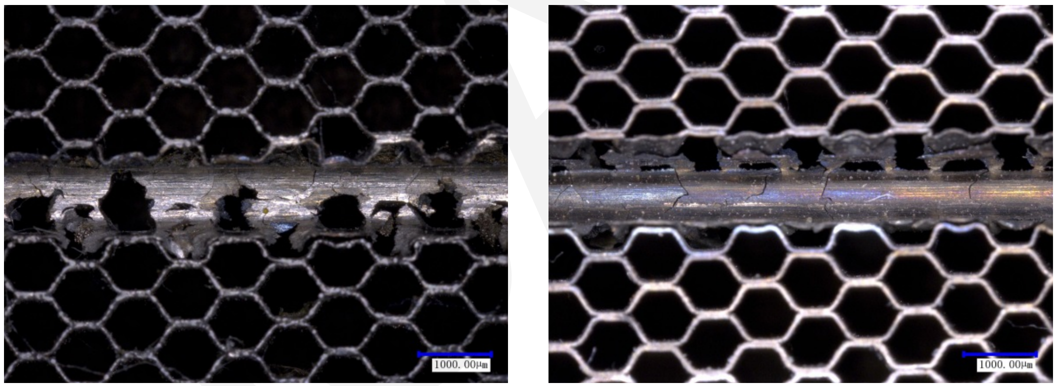
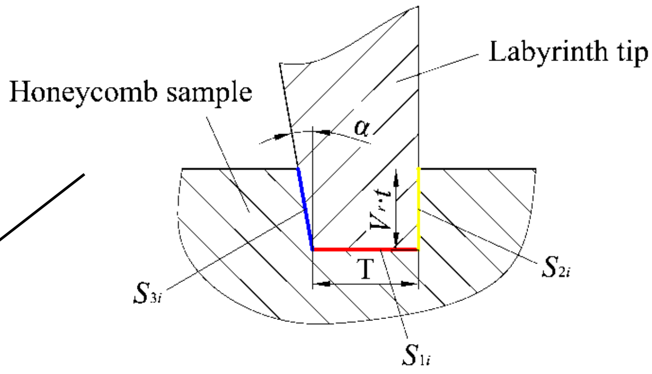


Fig.11 Details of blocked honeycomb for test 6# and 7#.

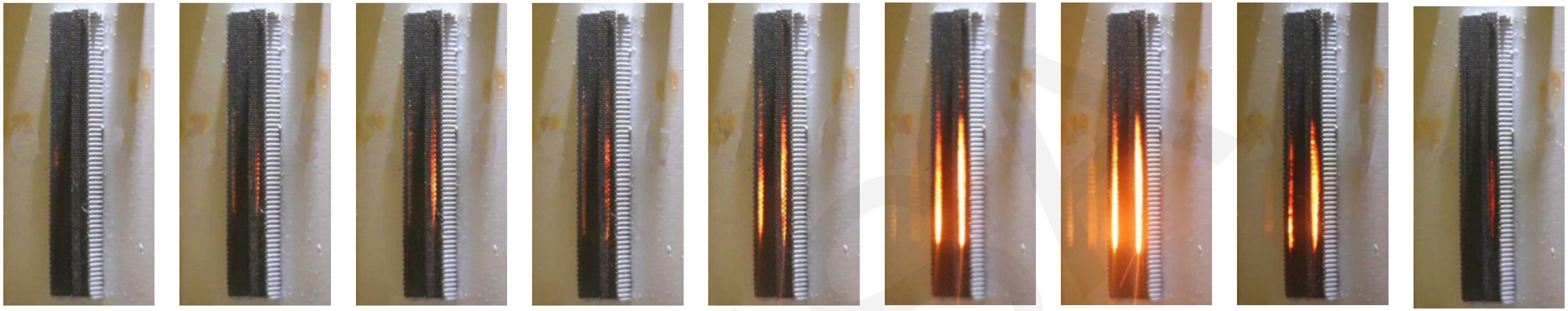
The total scraping area:

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

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

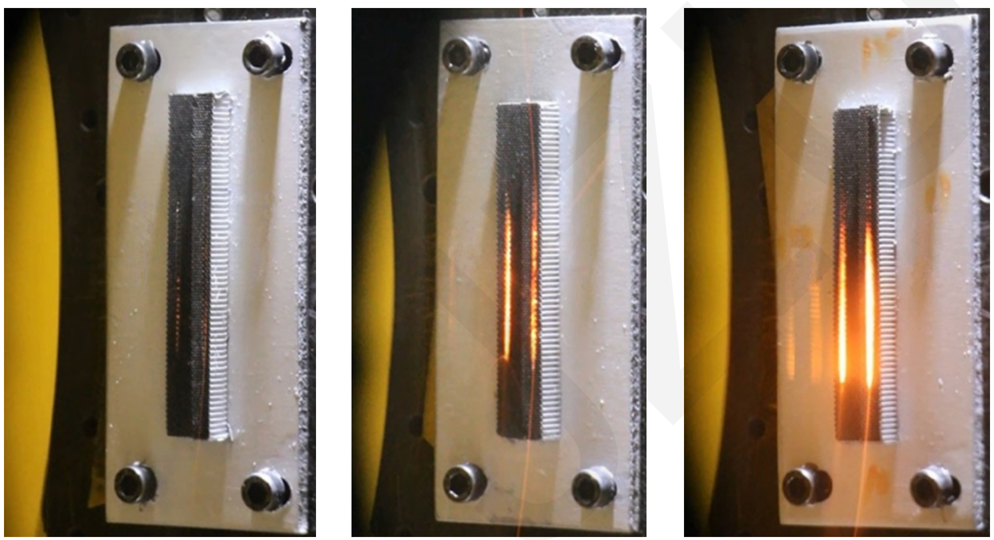


Test results and discussion



(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

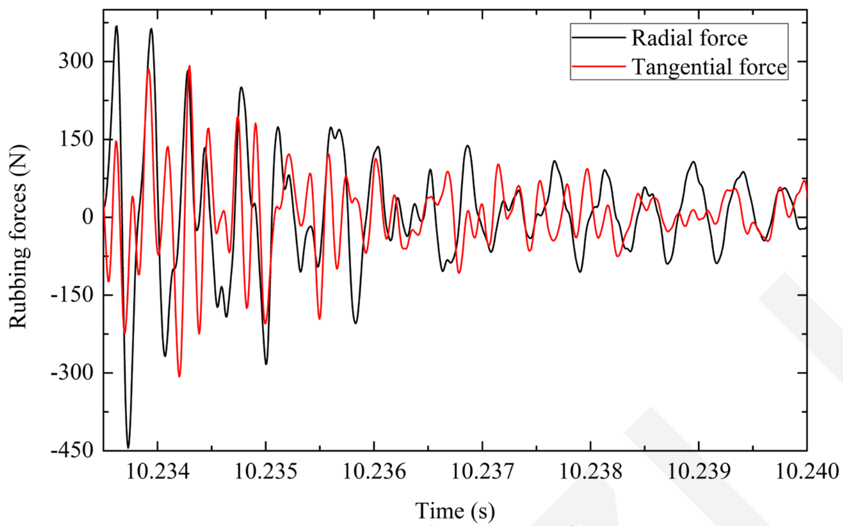


Fig.15 Typical rubbing forces for one rubbing cycle. (V_b= 300 m/s, V_r= 120 μm/s)

- 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.

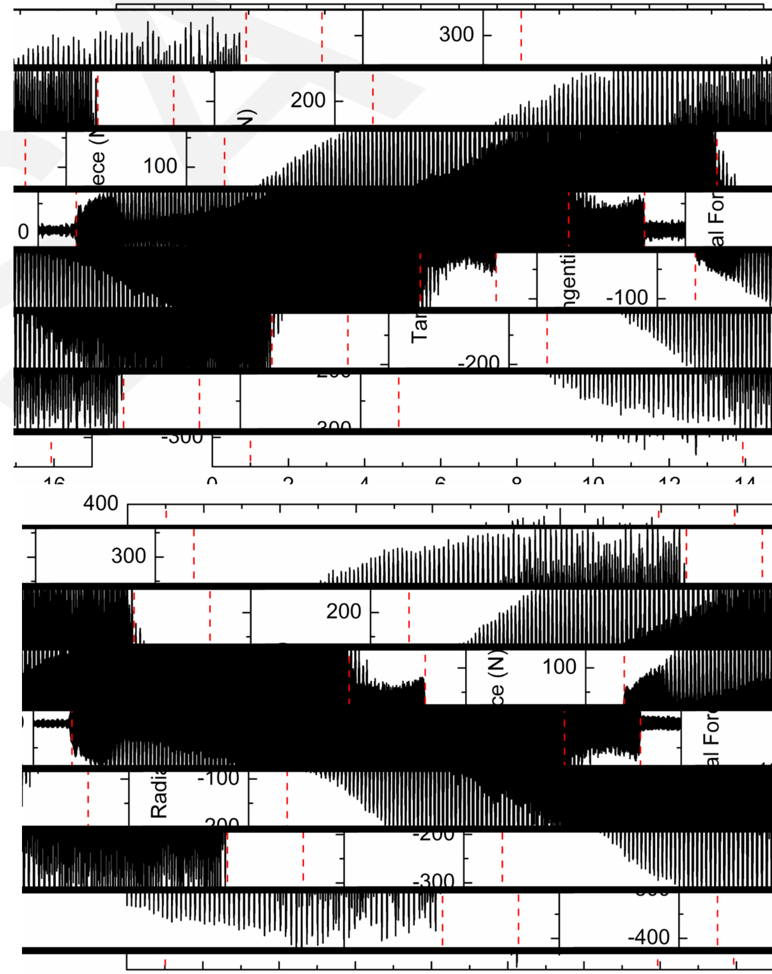


Fig.16 Tangential and radial forces recorded over the rubbing period.

Test results and discussion

■ Analysis of rubbing forces and accelerations

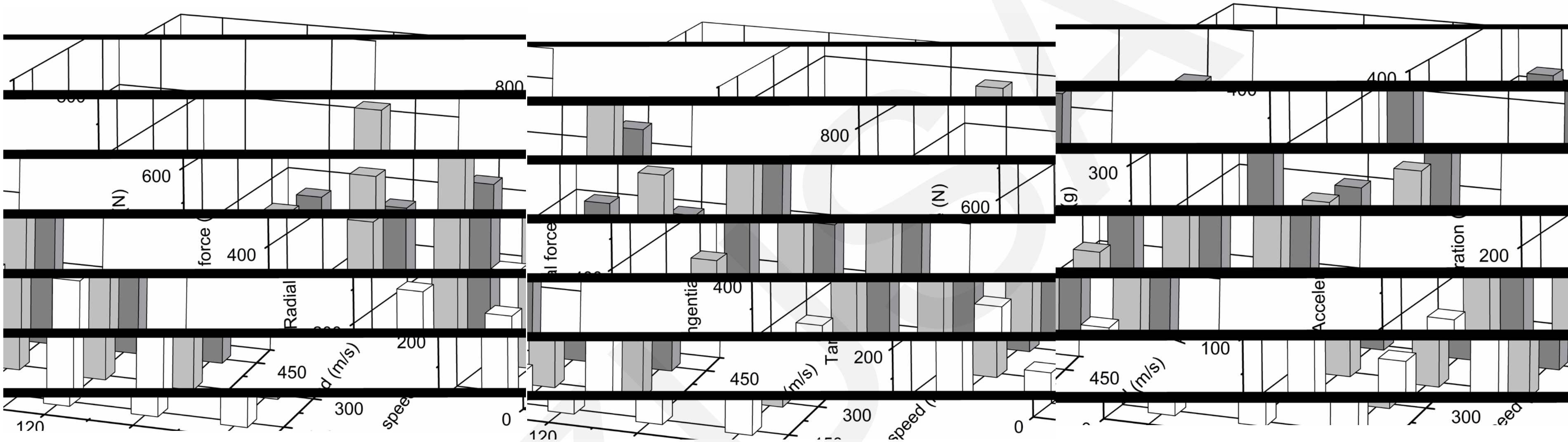


Fig.17 Maximum values of radial, tangential forces and acceleration for nine tests.

- 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.

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