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AFS (Agilent Floating Suspension) Technology
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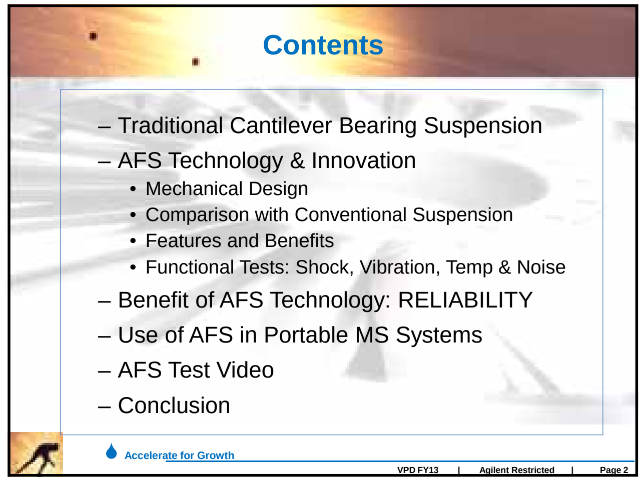
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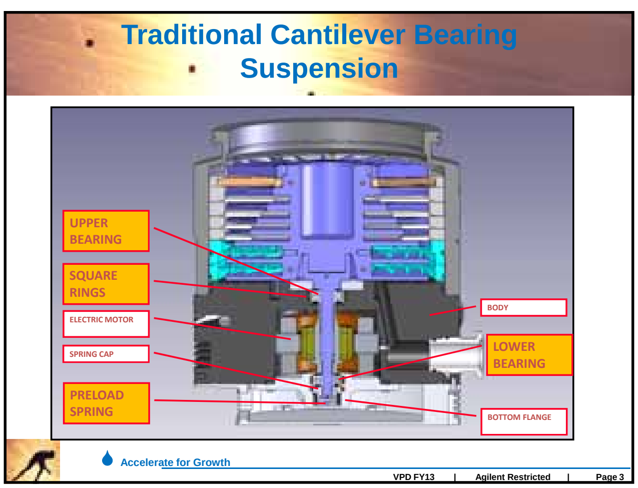
Traditional Cantilever Bearing Suspension
UPPER BEARING
SQUARE RINGS
ELECTRIC MOTOR
SPRING CAP
PRELOAD SPRING
BODY
LOWER BEARING
BOTTOM FLANGE
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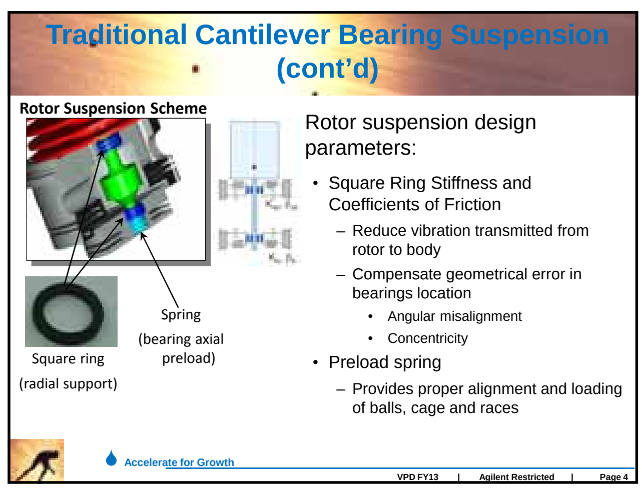
Traditional Cantilever Bearing Suspension (cont'd)
Rotor Suspension Scheme
Square ring
(radial support)
Spring
(bearing axial preload)
Rotor suspension design parameters:
• Square Ring Stiffness and Coefficients of Friction
– Reduce vibration transmitted from rotor to body
– Compensate geometrical error in bearings location
• Angular misalignment
• Concentricity
• Preload spring
– Provides proper alignment and loading of balls, cage and races
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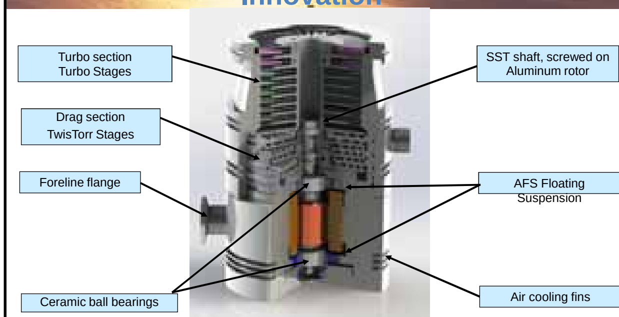
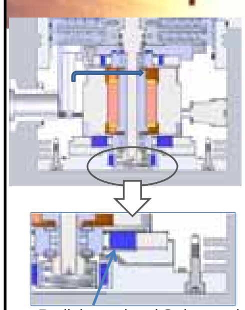
Agilent Floating Suspension Technology & Innovation



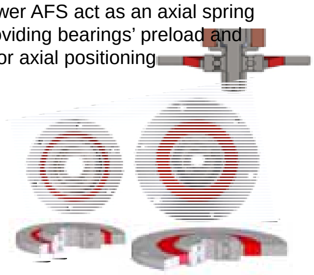
AFS: Mechanical Design

- SST shaft mechanically fastened to Al rotor to provide rotor stability (bending effect, behavior under external shock loads)
- Agilent Floating Suspension
  - Guaranteed bearing alignment (AFS components' geometrical precision)
  - Optimized rotor dynamics: balance & stability (through increased radial stiffness)
  - Constant bearing preload (lower AFS acts as an axial spring)
  - Excellent resistance to external shocks (tested up to 235 g)
  - Reduced acoustic noise
  - Thermal stability
  - Benefits are independent of orientation
  - Oil Free

AFS: Mechanical Design cont'd



- AFS geometrical precison guarantees perfect bearing alignment
- Designed radial stiffness, optimize rotor dynamic behaviour and acoustic noise
- Lower AFS act as an axial spring providing bearings' preload and rotor axial positioning



- Radial guard and S-ring made of new conductive material
- Spring for additional thermal contacts
  - lower bearing temperature

Mechanical Design Summary

- **Upper AFS** → better unbalance stability (both Axial/radial Stiffness)
  - Damping
  - Guarantee axial contact between bearing and soft shoulder
- **Lower AFS** → low fretting risk Axial/radial Stiffness
  - Damping
  - Guarantee bearings preload
- **New high-conductive rubber** → lower bearing temp
- **Additional thermal contacts** → lower bearing temp
- **New bearing (double shielded)** → higher MTTF
- **SST shaft** → lower deformation in resonance → lower unbalance
- **Conservative clearances calculation** → low crash risk

AFS vs Conventional Suspension

Upper bearing

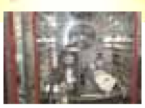
Lower bearing

Features and Benefits of AFS

- ✓ Continuous alignment and correct load to the bearings
- ✓ Ability for the rotor to adjust to external forces
- ✓ Superior resistance to outside shocks and vibrations
  - Tested to 230 g in drop tests while running
- ✓ Reduction from 5 tunable components to 2 tunable components
- ✓ Scalability of the AFS system over a wide range of rotor/ pump sizes
- ✓ Improved reliability by design
- ✓ Reduced noise and vibration levels emitted from the pump

AFS: Functional Testing

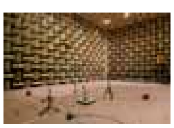
Shock test



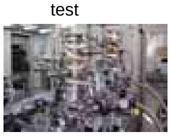
Temperature test

Humidity test

Vibration test



Acoustic test



Vacuum test

Reliability assessment on MSD system

Life Tests

Vibration Test

4 Pumps tested in horizontal, vertical and upside position

Pump position	Operative (5-500Hz)	Non-Operative (5-500Hz)
Horizontal	0.2grms	2grms
Vertical	0.2grms	2grms
Upside-down	0.2grms	2grms

Operative: Pump tested in nominal working conditions(pump ON). After the test the pump must be able to work as good as new.
Non Operative: Pump not running (pump OFF) to simulate transportation and storage. The pump after the test must work as good as new.

Temperature Test

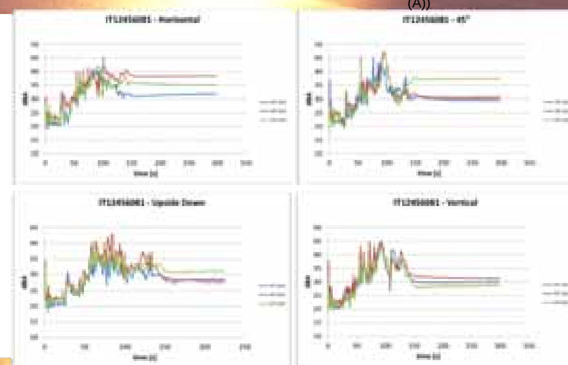
4 Pumps tested in horizontal, vertical and upside position.

Pump position	Operative	Non-Operative
Horizontal	0°C to 40°C	-40°C to +70°C
Vertical	0°C to 40°C	-40°C to +70°C
Entire thermal cycle = 80 hours		

Operative: Pump tested in nominal working conditions(pump ON). After the test the pump must be able to work as good as new.
Non Operative: Pump not running (pump OFF) to simulate transportation and storage. The pump after the test must work as good as new.

Noise Test

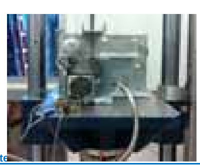
Noise specs are measured at full speed at 1meter from the pump (noise specs < 50dB (A))



Reliability assessment tests on Agilent GCMS

- **Non-operational shock test:** system drop with pump not running, after each drop pump is switched on and after stabilization unbalance, Fourier spectra, power adsorption and bearing temperature are acquired.

# shock	1	2	3	4
TV301 IT12186116	pass	pass	pass	pass
TV301 IT12196067	pass	pass	pass	pass
TV301 IT12166229	pass	pass	pass	fail
304 - LP 13	pass	pass	pass	pass
304 - LP 15	pass	pass	pass	pass
304 - LP 16	pass	pass	pass	pass
304 - LP 14	pass	pass	pass	pass



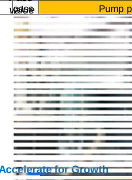
Reliability assessment tests on Agilent GCMS

- **Operational shock test:** system drop with pump running, after each drop unbalance, Fourier spectra, power adsorption and bearing temperature are acquired.

Increasing drop height

# shock	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18...		25
Height (inches)	3	3	3	3	3	3	3	3	3	3	3.1	3.2	3.3	3.4	3.6	3.8	4	4.3...		10
TV301 IT12186116	crash																			
TV301 IT12196067	crash																			
TV301 IT12166229	crash																			
304 - LP 13	pass	pass	pass	pass	crash															
304 - LP 15	pass	crash																		
304 - LP 16	pass	Pump perfectly working but unbalance above baseline																		
304 - LP 14	pass	Pump perfectly working but unbalance above baseline																crash		

Pass = value



Reliability assessment results (3)

- **Non-operational shock test**
- **Test description:** after each drop (pump not running), pumps is switched on and after 13 minutes (time for stabilization) unbalance, Fourier spectra, power adsorption and bearing temperature are acquired.
- **Test results**

Non-operational shock test

# shock	1	2+3	4+5+6	7+8+9
Traditional suspension 1	pass	pass	pass	pass
Traditional suspension 2	pass	pass	pass	pass
Traditional suspension 3	pass	pass	pass	fail
AFS 1	pass	pass	pass	pass
AFS 2	pass	pass	pass	pass
AFS 3	pass	pass	pass	pass
AFS 4	pass	pass	pass	pass

Unbalance > baseline value +0.4 m/s²

Reliability assessment results (4)

- **Operational shock test**
- **Test description:** after each drop (pump running) unbalance, Fourier spectra, power adsorption and bearing temperature are acquired.
- **Test results**

# shock	1
height (inches)	3
Traditional 1	crash
Traditional 2	crash
Traditional 3	crash
AFS 1	pass
AFS 2	pass
AFS 3	pass
AFS 4	pass

Pump destroyed

On going Life Tests

20 pumps in accelerated life test since September 2012.

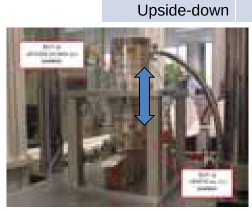
All pumps still working as of today (end of August 2013)

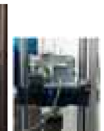
- Pumps operating 24/7 at 55°C under argon gas load.
- Ambient temperature 25°C.
- Power > 100W
- Pumps stopped once a day under vacuum in 45 minutes staying on resonances frequencies for most of the time.

Shock Test

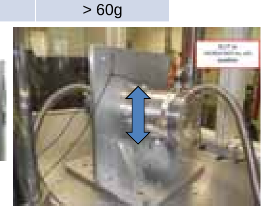
Pump position	Sinusoidal (Operative)	Trapezoidal (Non-Operative)
Horizontal	> 110g	> 40g
Vertical	> 150g	> 60g
Upside-down	> 150g	> 60g

4 Pumps tested in each position.





Click To Start Video



Operative: Pump tested in nominal working conditions(pump ON). After the test the pump must be able to work as good as new.
Non Operative: Pump not running (pump OFF) to simulate transportation and storage. The pump after the test must work as good as new.

AFS use in Portable Mass Spectrometry Applications

- AFS represents a major step towards allowing Turbo Pumps to meet the needs of HEMS instruments:
  - Ruggedness
  - Reliability by Design
  - High Performance
  - Resistance to Impacts
  - Universal Orientation
  - Reduced Power
  - Reduced Noise & Vibration