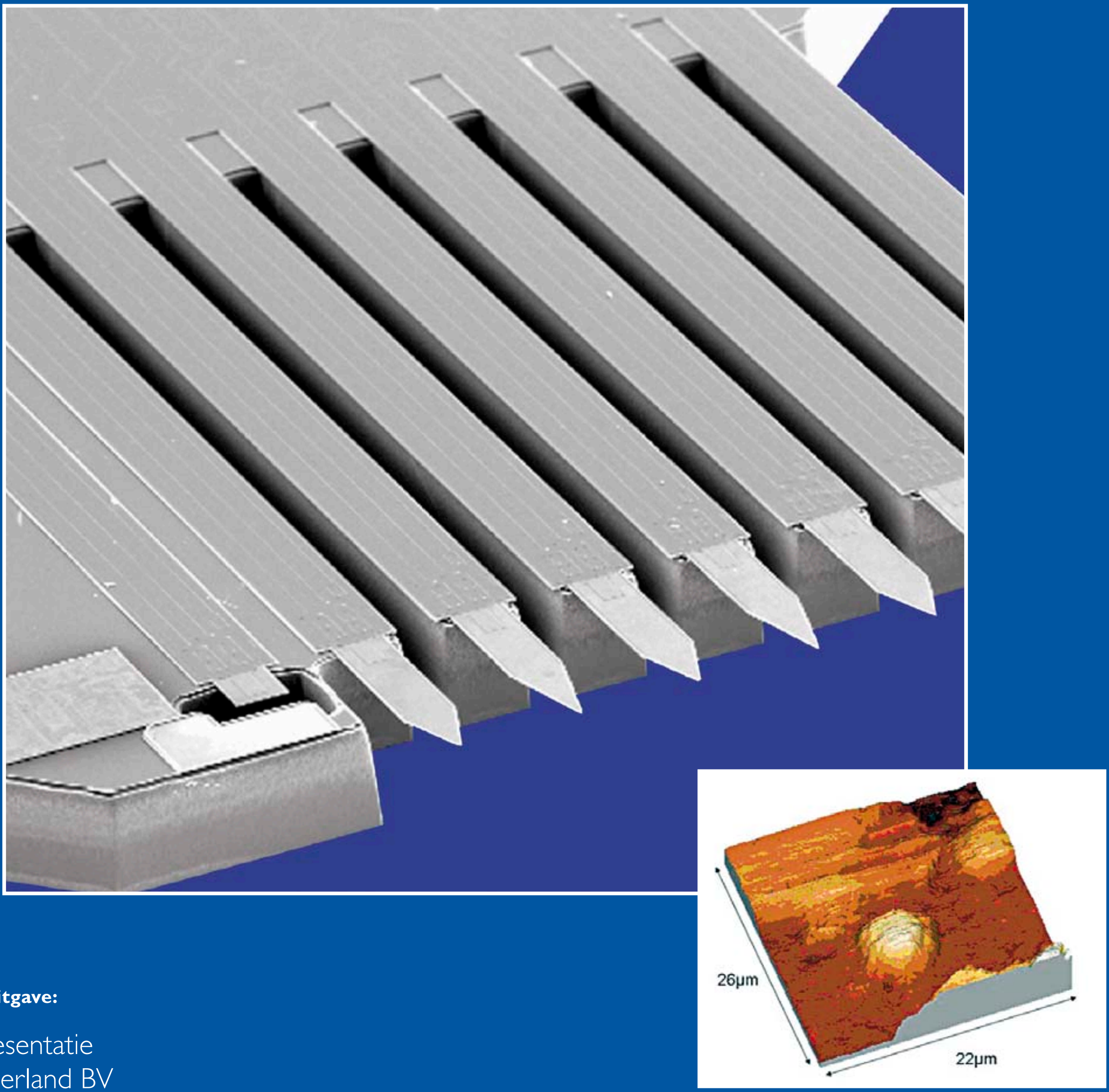
NEVAC *blad*

JAARGANG 47 / UITGAVE 3

Orgaan van de Nederlandse Vacuumvereniging

Atomic Force Microscopy on Mars



Verder in de uitgave:

- Bedrijfspresentatie BOA Nederland BV

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Op de voorpagina

Het grote figuur op de cover toont de cantilevers van het Atomic Force Microscopy systeem binnen de Phoenix Mars Lander.
Dit systeem leverde de eerste AFM opnamen van gronddeeltjes van Mars zoals in het kleine figuur getoond wordt.

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Contributies

Contributie € 18,- per jaar
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Studenten/promovendi € 4,50 per jaar

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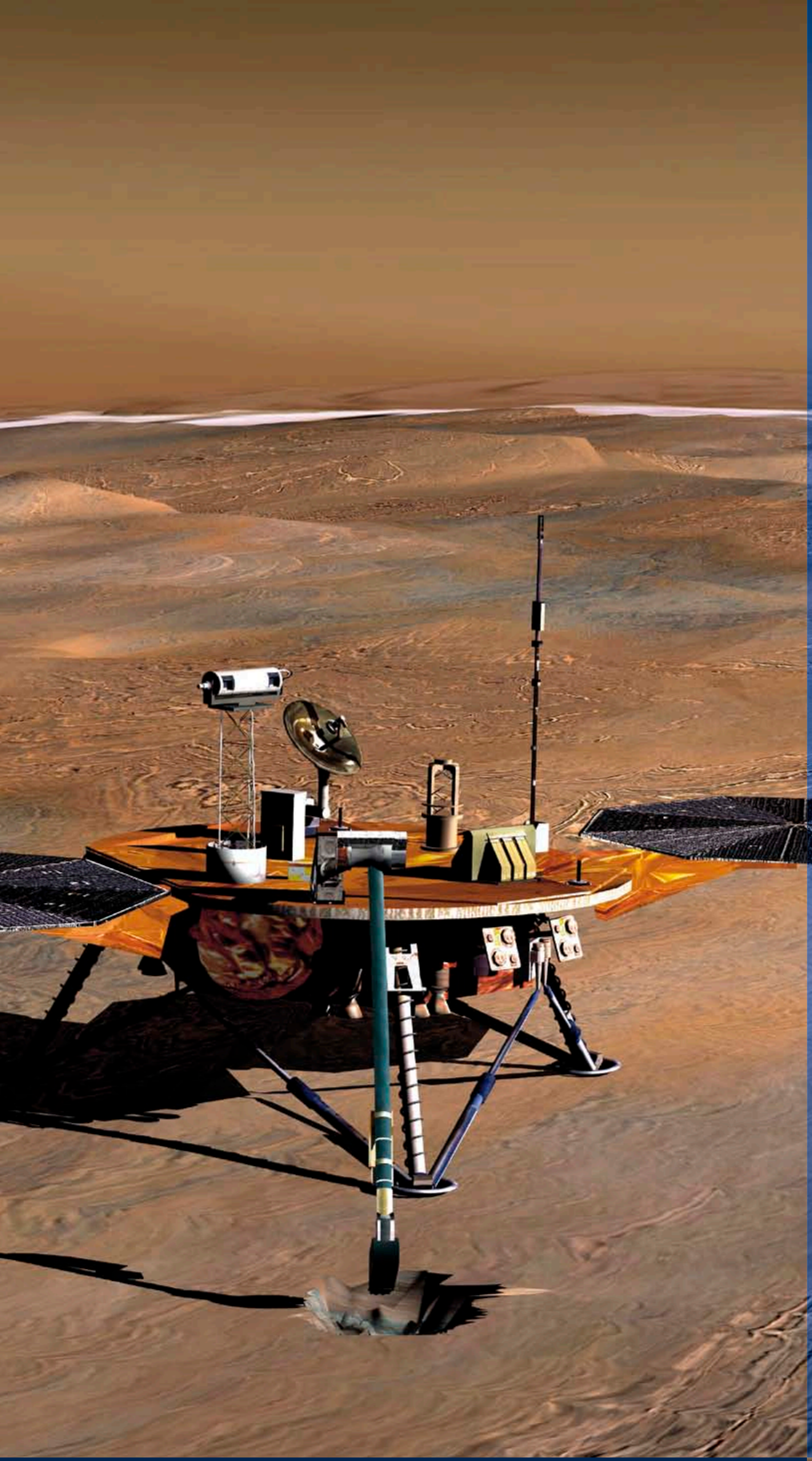

Redactioneel

Dit derde nummer van 2009 bevat een uitgebreid artikel over de ontwikkeling van een atomic force microscope (AFM) die ingebouwd is in de Phoenix Mars Lander.

De Phoenix Mars Lander missie onderzocht de geologie, het klimaat, en de geschiedenis van het water in de noordelijke arctische regio van Mars van 25 mei tot 2 november 2008. Voor de eerste keer was ook een AFM experiment opgenomen in een dergelijke planetaire wetenschappelijke missie.
De ontwikkeling van het AFM systeem is in belangrijke mate gedaan onder leiding van Prof. Urs Staufer van de Technische Universiteit Delft (Micro and Nano Engineering Laboratory van de faculteit 3ME).
Tevens bevat dit nummer een korte Bedrijfspresentatie van BOA Nederland BV. BOA richt zich met name op het ontwerp en fabricage van flexibele componenten voor onder andere vacuum systemen.

Bij de totstandkoming van dit NEVACblad is opnieuw gebleken dat het uiterst moeilijk is om aan kopij voor het blad te komen. We hebben zeer veel personen die werkzaam zijn bij de universiteiten in Nederland en daarbij ook een relatie hebben met vacuum benaderd voor het schrijven van een artikel.
Ook hebben we mailings naar de bedrijfsleden van NEVAC verzonden met een oproep om kopij te leveren.

De respons is over het algemeen teleurstellend. Bij deze willen we dus een klemmend beroep doen op de lezer om kopij in te sturen, waar ook een vergoeding (van €20 per afgedrukte pagina) tegenover kan staan.
Met name studenten die afstuderen op een onderwerp, waarbij vacuum een essentieel onderdeel vormt, zouden (door hun begeleiders) sterk aangemoedigd moeten worden om een artikel in te sturen.

De sluitingsdatum van kopij voor het
eerste nummer van het NEVAC-blad 2010
is 12 januari 2010.

Scanning Force Microscope for Planetary Research on Mars

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The Phoenix Lander Mission investigated the geology, the climate, and the history of water in the northern arctic region of Mars from May 25 till November 2, 2008. For the first time, also a microscopy experiment was included in such a robotic planetary science mission. The low atmospheric pressure (~ 10mbar) and large temperature variations (~ 60 deg C) required special design solutions for the scanner of the instrument. In order to avoid electrical discharges, a low voltage Lorenz actuator was employed rather than the usual piezo-electric scanner. The damping was achieved by means of internal friction of the spring suspension. The instrument was successfully operated on Mars and produced the first high resolution images of Martian soil particles.

Introduction

The soil at the top of the surface of a planet forms an interesting interface between the ground and the atmosphere. It is the zone where gases are exchanged, where erosion takes place, and where light and heat as energy sources e.g. for life, are available. Water on Mars is currently only stable as a gas or a solid. A relatively thin soil layer of a few centimeters stabilizes the water-ice table in the north polar region of Mars as observed from orbit[1]. This thin layer was considered as an interesting niche with a high biopotential, because it should be regularly flushed by water vapor, which might occasionally condense in a temporary thin liquid layer. Biopotential, in this context, means the potential that life-enabling conditions could have at least temporarily existed. The Mars mission Phoenix[2] set out to this area to pursue these and other questions linked to water.

Phoenix had for the first time a dedicated microscopy station on board in order to investigate the soil particle size, size distribution, shape and texture. Light scattering experiments conducted by the Viking and MER missions indicated that airborne dust, which eventually settles and becomes part of the top surface layer, has a particle diameter of one to a few micrometers. Scanning force microscopy or AFM (Atomic Force Microscopy) is a high resolution three-dimensional imaging method, having a resolution comparable to electron microscopy. It works on conductive and non-conductive samples.
It was therefore decided to take besides an optical microscope (OM) also an AFM on board of Phoenix.

The AFM is an instrument which probes the sample in a raster like fashion by means of a sharp stylus, which is mounted on the free end of a single side clamped cantilever spring[3]. There are two different ways of operating an AFM, in static or in dynamic mode. In static mode, the cantilever spring is slightly deflected due to the force acting through the tip. One method to measure the bending of the cantilever is to integrate a

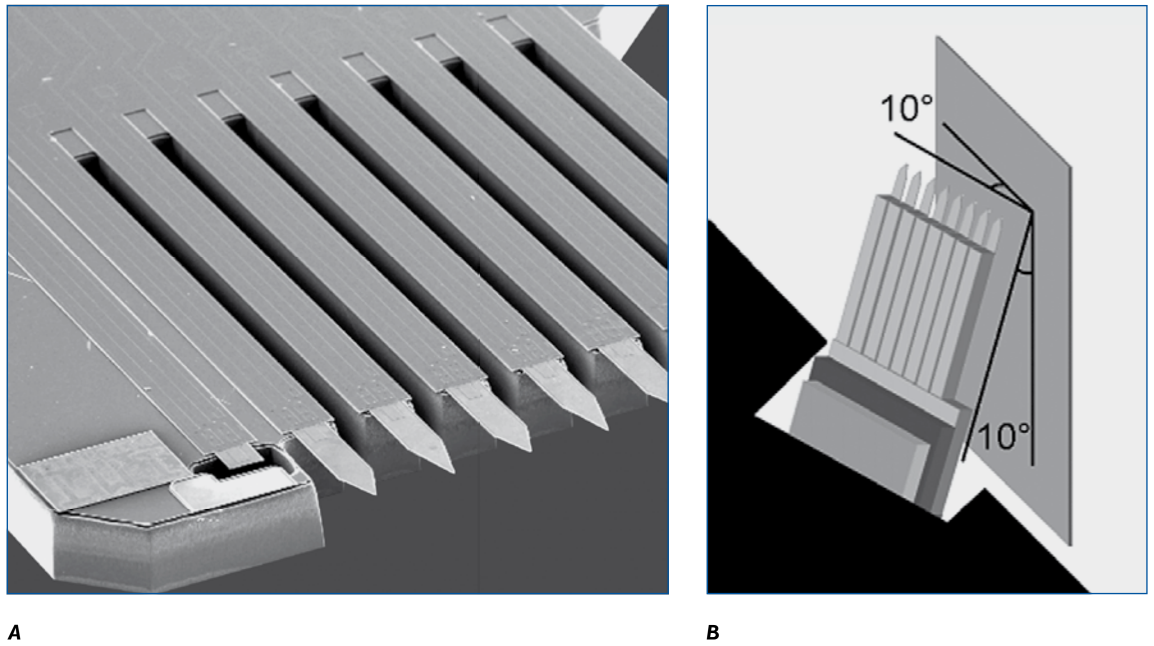


Figure 1 a) AFM chip showing 8 cantilevers for redundancy. The small, 9th cantilever to the left features a reference piezoresistor for compensating temperature effects. b) Schematic presentation of how the cantilever chip is mounted for scanning a substrate with one tip at the time. The long support beams were needed to cleave the cantilevers fare away enough to avoid touching the sample with the body of the chip after the first levers will had been removed.

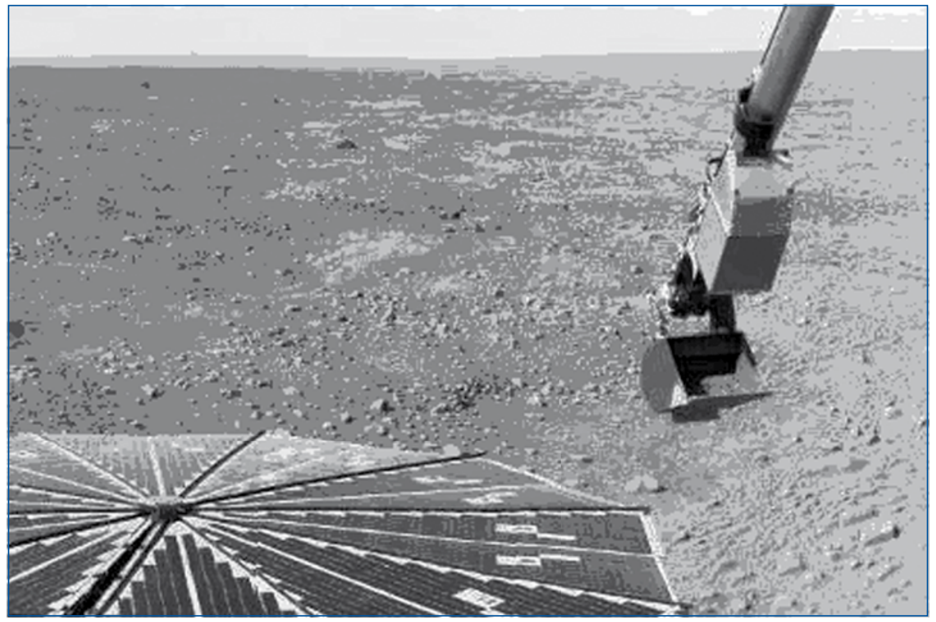


Figure 2 The robot arm has acquired a soil sample in the scoop and is on its way to deliver it to the microscopy station. (Image credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University).

piezo-resistive strain gauge[4].

The deflection is kept constant by means of a feedback loop and a servo-mechanism such that iso-interaction-force contours or topographs can be measured of the sample. In the dynamic mode, the cantilever is vibrated at one of its resonance frequencies. If the tip senses a force gradient due to the interaction with the sample, the resonance frequency detunes and the vibration amplitude is damped. The damping effect can be easily measured and is used to control the averaged tip-to-sample distance. Averaged means here averaged over several oscillation cycles of the cantilever, which has a typical resonance frequency of several 10's of kHz to 100kHz. This so-called "amplitude modulation" or "tapping" mode is very suitable for conducting experiments in air. When running the instrument in vacuum, however, the quality factor of the cantilever spring is usually very high, and hence the amplitude does not ring down fast enough. In that case, frequency modulation (FM) can be used, where one regulates on a constant phase difference between excitation signal and cantilever vibration. The environmental conditions on Mars are comparable to rough vacuum (about 10 mbar) such that only static mode and dynamic FM AFM are conceivable.

The AFM tip can easily modify the sample and push loose particles around. In the past, it was therefore only rarely used for analyzing soil, and then the particles were almost always fixed to a substrate by means of adhesive.[5] Lateral forces are somewhat reduced in dynamic mode AFM because the tip is only in close proximity to the sample during a very short period. That was the reason for selecting dynamic FM AFM as the principle operation mode for the Phoenix AFM.

Concept of the Experiment

An AFM cantilever is vulnerable and the tip can easily be contaminated. In order to provide redundancy, the Mars AFM chip contained 8 cantilevers (c.f. Figure 1), which could be cleaved off and sequentially operated.

To enable this the chip was mounted with two tilt-angles relative to the substrate such that only one tip could get onto the measuring position at a time. Once broken or contaminated, the cantilever was removed by means of a special cleaving tool on the substrate wheel, making place for the next one.[6]

The samples were acquired by means of a robot arm[7] (c.f. Figure 2) and delivered to a substrate wheel, which was mounted on a rotation and translation stage. The latter allowed moving a set of 6 substrates at a time outside the enclosure of the microscopy station for receiving the sample. It was then pulled back into the box and rotated in front of the microscopes. A set of optical microscope images were acquired, sent to Earth and analyzed. Based on that, areas of interest for AFM imaging could be selected. The translation and rotation stage was then used to fine position the sample and perform the approach of the substrate to the AFM cantilever. For full details about the Phoenix AFM experimental procedure, the reader is referred to a paper by M. Hecht et al.[8].

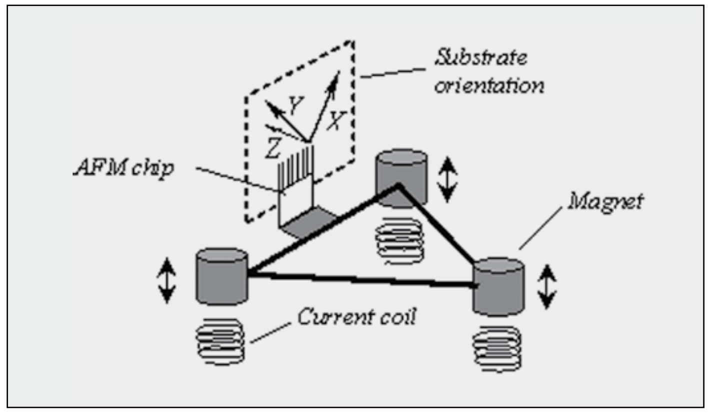


Figure 3 Principle of the voice coil actuator.

Instrument Design

Some of the design criteria became apparent in the introduction. Others were more linked to the journey to Mars. The most prominent of those were the vibrations during take-off and the shocks, which can reach up to 25,000 m/s^2 during separation from the back-shell and the heat-shield in the final entry descent and landing phase. Also related to the transport were the restrictions in mass. The scanner weighted 17 g and the electronic controller 190 g.

The major external constraints during operations were the huge temperature variations and the reduced atmospheric pressure on Mars. Diurnal temperature cycles could reach from about -100 to +20 Celsius. Full operation were limited to above - 45 Celsius. The Martian atmosphere comprises mainly CO_2 at a pressure of around 10mbar, which bears the risk of supporting corona discharges even at moderate potential differences.[9]

This directed the design of the scanner away from the classic piezo-electric actuator towards a Lorentz or voice coil actuator, which will be further detailed in this paper. The second motivation for this choice was that a scan range of about 50µm in x and y and about 10 to 15 µm in z direction was required. Piezo actuators, which could provide this stroke, are quite large and fragile, risking breakage during the harsh cruise conditions.

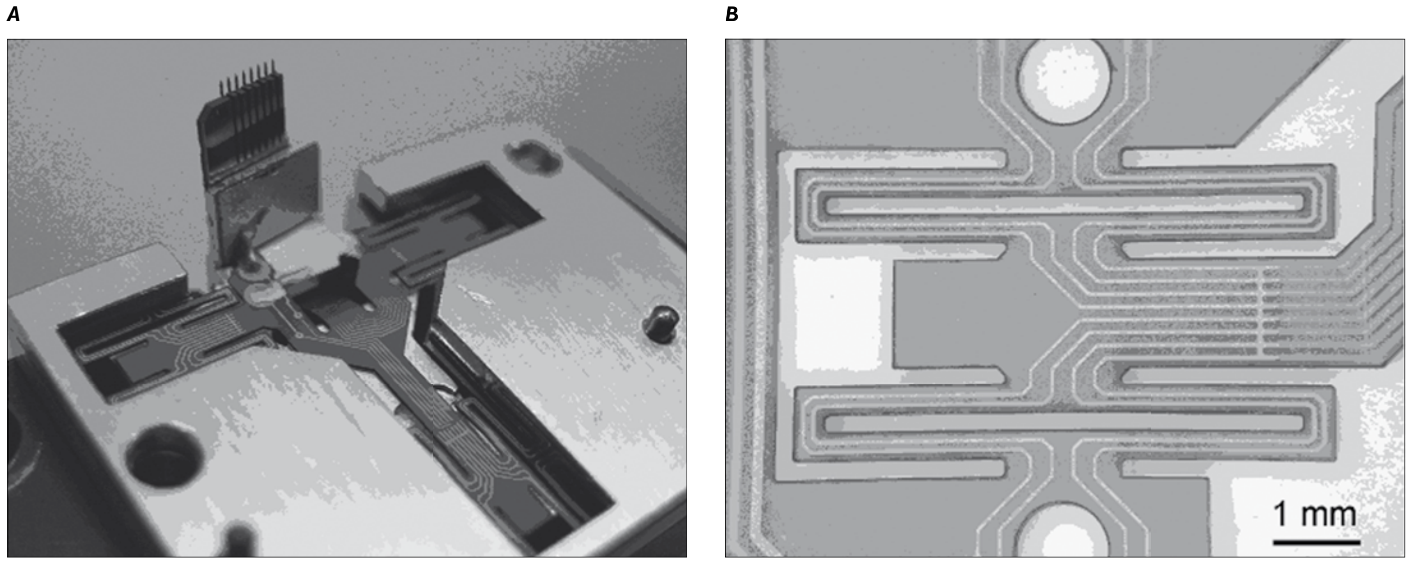


Figure 4 a) View of one out of three polyimide springs with integrated electrical conduits. The copper lines on the visible side were designed to compensate the bimorph effect. The electrical connections were established by means of the copper lines on the hidden side. One of the corners of the platform will be glued to the central piece between the two horizontal ovals. b) The springs can be recognized at the ends of the T-shaped opening in the top plate of the scanner after the cover was removed.

The concept of the scanner relied on three voice coils driven by currents of up to 20 mA (c.f. Figure 3). Permanent FeNdB magnets were fixed above them to a triangular platform, which was suspended by spring leafs to counterbalance the electromagnetic forces. Deflecting all magnets upwards by passing a current through the coils could generate the x motion, moving the front left one downwards and the right one upwards while keeping the back at rest could generate a y motion, and keeping the two front ones at rest while moving the back one could generate a z motion. In the final implementation, the x and y axis were chosen differently i.e. at an angle of 45 degrees to achieve a more symmetric condition. Hence, all movements were coupled to all actuators. This linked and limited the largest z range at the maximal x-y scan range. A maximal scan range of 65µm x 65µm was achieved at which the range in z direction was 8 µm. At a reduced x-y range of 20 µm or less, the z range increased to 13 µm. These values were all measured at room temperature under laboratory conditions.

The springs, on which the scanner platform was suspended and which counter balanced the electro-magnetic forces, needed to be damped in order to avoid ringing and to allow reasonably fast scan speeds. Vacuum-compatible grease could have been used for this purpose. Unfortunately, the large range of operation temperatures rendered this solution difficult to implement: the viscosity of the available greases varies too much, giving rise to extreme non-linear scanning performance. The solution was the exploitation of the internal friction of springs with a low quality-factor. Polyimide, as used in so called "flex-prints" for mounting electrical circuits, has a reasonable high loss factor and offered the additional advantage that we could integrate electrical conduits. This last feature was very attractive because we needed a total of 13 electrical signals to carry to the scanner platform to contact all the sensors of the 8 cantilevers and the reference resistor plus the signals for defining the tip potential and driving a dither-piezo for exiting cantilever resonances in the dynamic operation mode. Each of the three spring systems (c.f. Figure 4) could carry two times 4 lines. Compared to a stainless steel spring of equivalent compliance, such a solution had a two-times-lower quality factor.

Figure 5 shows measurements of transients at different temperature to illustrate the damping. Ideally, critical damping would be desired, which is obviously not achieved with the selected solution. However, it still allowed operation of the stage at about 3 seconds/line or about 12ms/point. This yielded a frame rate of about 0.08 min^{-1}, which was judged acceptable from an operations point of view. The complete, assembled scanner is shown on Figure 6. Prior to launch, the

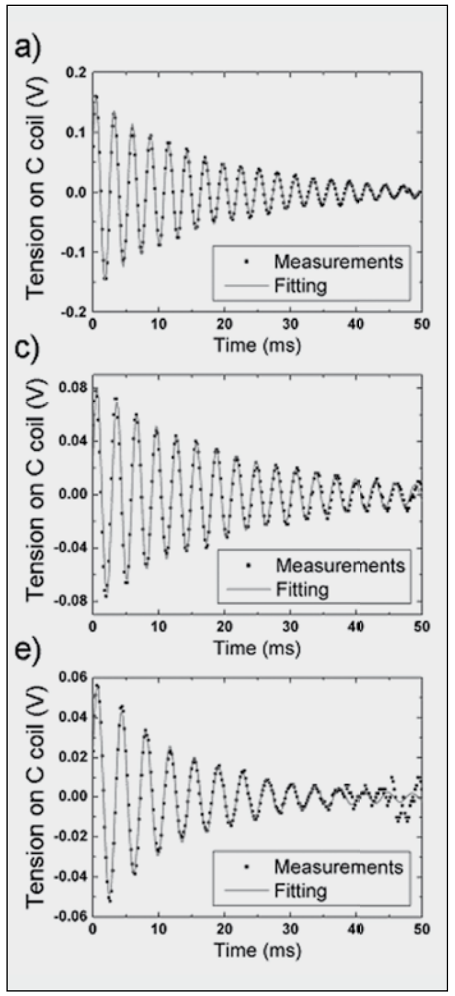
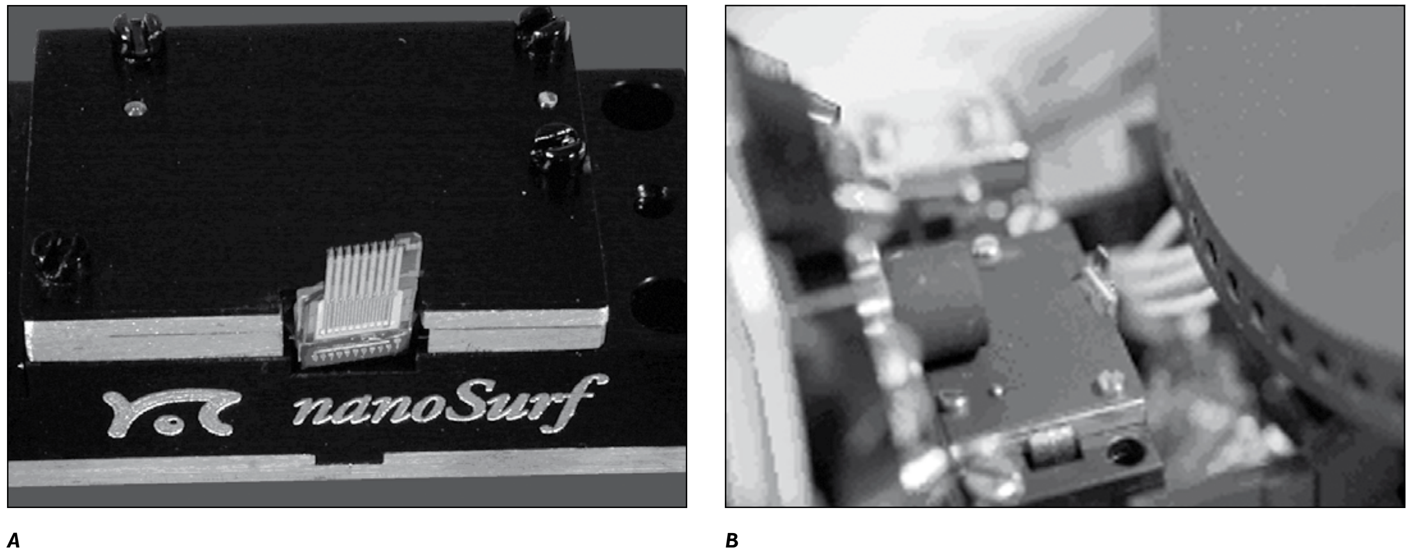


Figure 5 Damped oscillations on the C-coil after that the actuators had been switched off.
The dots represent the data from the oscilloscope and the curve the best fitting based on the solution of the damped harmonic oscillator. The images show the damped oscillations at a) -128 deg C, b) -40 deg C and c) +20 deg C.

Figure 6 a) Assembled AFM scanner. b) Integrated instruments inside the microscopy station.



scan characteristics were assessed at different temperatures.

Figure 7a) shows an example of an image taken on Earth from a calibration grid and for comparison 7b) shows a calibration grid recorded on Mars. The latter was recorded with the second tip after successful removal of the first cantilever. Figure 8 shows an example of soil particles measured on Mars.

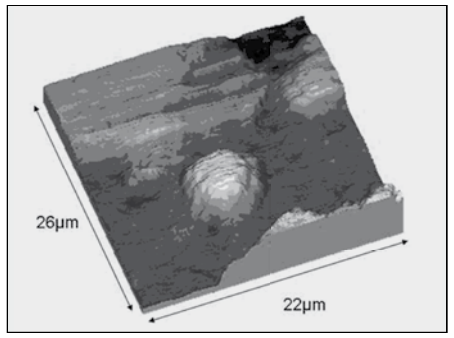
Conclusion

The concept of the voice coil actuators and internally damped polyimide springs proved successful both in the laboratory as well as on Mars. For the first time, scanning force microscope images could be recorded on another planet which opens a new era in planetology.

Acknowledgements

This work was supported by financial grants from the Wolfermann-Nägeli Foundation (CH), the Swiss priority program MINAST, the Space Center at EPFL (CH), the Republic and Canton of Neuchatel (CH) (CH), STFC (UK), and the NASA through the Phoenix Mission (USA). We would like to acknowledge P. Smith and the Phoenix Science and Engineering Teams for many helpful discussions.

Figure 8 Martian soil particles as observed by the Phoenix AFM showing 4 particles. The spheroidal particle in the center is 8 μm in diameter, above it a plate-like particle is seen, the other two cross the image boundary. (Image taken from [2], online supporting material, reprinted with permission of Science).



Endnotes

[1] W. Boyinton Science, 297, 81 (2002).

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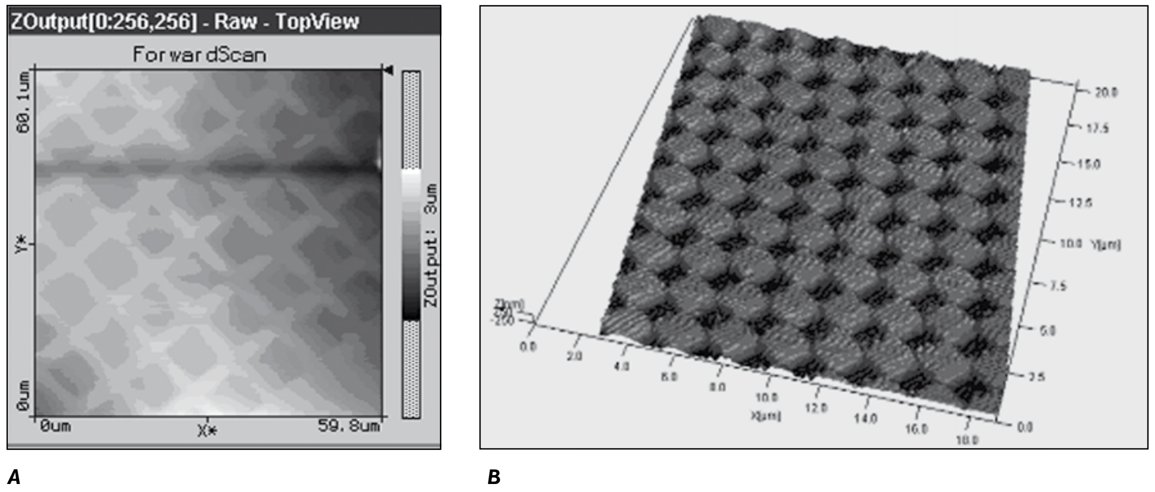
Figure 7 a) Grey-scale AFM image of a calibration grid recorded with the flight model of the Mars AFM prior to launch. b) Checker-board calibration sample imaged on Mars after having successfully removed the first cantilever.



Press release

Bedrijfspresentatie BOA Nederland BV

BOA richt zich op het ontwerp en fabricage van flexibele leiding- en systeem-technologie. BOA is actief in vele marktsegmenten, uiteenlopend van de installatietechniek, de (petro-) chemische industrie en de levensmiddelentechnologie, tot en met high tech toepassingen in ondermeer de halfgeleider- en medische industrie.

BOA ontwerpt en maakt voor deze toepassingen compensatoren, balgen, slangen en complete (sub-) samenstellingen. De BOA Group is een internationale organisatie met diverse fabricage-locaties in Europa en daarbuiten. BOA Nederland BV is binnen de BOA Group het competence centre op het gebied van schoon produceren en cleanroom techniek.

Het marktsegment vacuümtechniek heeft een groot aandeel binnen de totaal omzet van de BOA Group. Binnen dit marktsegment levert BOA oplossingen voor klanten uit onder andere de volgende toepassingsgebieden:
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BOA beschikt over hoogwaardige faciliteiten als het gaat om engineering. Op basis van de wensen en eisen van de klant wordt een passende oplossing geboden, hetzij als standaard component, of als compleet “custom made” maatwerk. Daarbij verschuiven de leveringen meer en meer van componenten naar samenstellingen. Deze kunnen compleet werkend en getest opgeleverd worden.

Voor de fabricage staan diverse faciliteiten ter beschikking. De kern-competenties van BOA zijn het verwerken van (zeer-) dunwandig RVS, hoogwaardig laswerk, reiniging, testen en assemblage. Dit alles in een schone omgeving en volgens de geldende (cleanroom-) voorschriften.

De basis van de flexibele elementen van BOA wordt gevormd door RVS precisie bandmateriaal, met een wanddikte vanaf 0,08 mm. Dit wordt volgens een uniek procedé gevormd tot een buis, en daarna geprofileerd. Tijdens deze stap worden de golven in de buis aangebracht die de BOA producten hun bekende flexibiliteit geven.

Het nu ontstane flexibele element wordt samengebouwd met de zgn. aansluitdelen waardoor een compleet en inbouw-klaar product ontstaan. Deze aansluitdelen worden op het flexibele element gemonteerd met behulp van verschillende moderne lastechnieken. Zuiverheid, nauwkeurigheid en proceskwaliteit zijn hierin enkele belangrijke begrippen.

De BOA flexibele producten worden meer en meer gecompleteerd en samengebouwd tot (sub-) samenstellingen. Daarbij worden ondermeer sensoren, bekabeling en beugels met de slangen of balgen samengebouwd.

Elk BOA product wordt nauwkeurig getest om vast te stellen of deze aan de geldende specificaties voldoet. U kunt hierbij denken aan dichtheid- en drukbeproeving en helium lektesten, maar ook aan functionele tests en de controle op de reinheid.

De reinheid van de BOA producten heeft de laatste jaren een grote vlucht genomen. BOA ontwikkelde een eigen reinigingsmethode én een eigen reinigingsmiddel waarmee de producten zeer zuiver worden. De mate van reinheid kan op verschillende manieren gemeten worden. Zo kunnen in eigen huis ondermeer particles gemeten en gedetecteerd worden.

Voor de afmontage, het testen en het verpakken van hoogwaardige onderdelen beschikt BOA over cleanroom faciliteiten volgens klasse 5, 6 en 7 volgens de EN-ISO 14644.

Natuurlijk worden de BOA producten ook voorzien van labels en verpakking conform de geldende klantwensen.

De BOA organisatie

De BOA organisatie is geheel gecertificeerd volgens EN-ISO 9001. Alle processen liggen vast in nauwkeurige procedures waardoor een hoge en constante mate van kwaliteit gewaarborgd is.

Meer informatie is te vinden op
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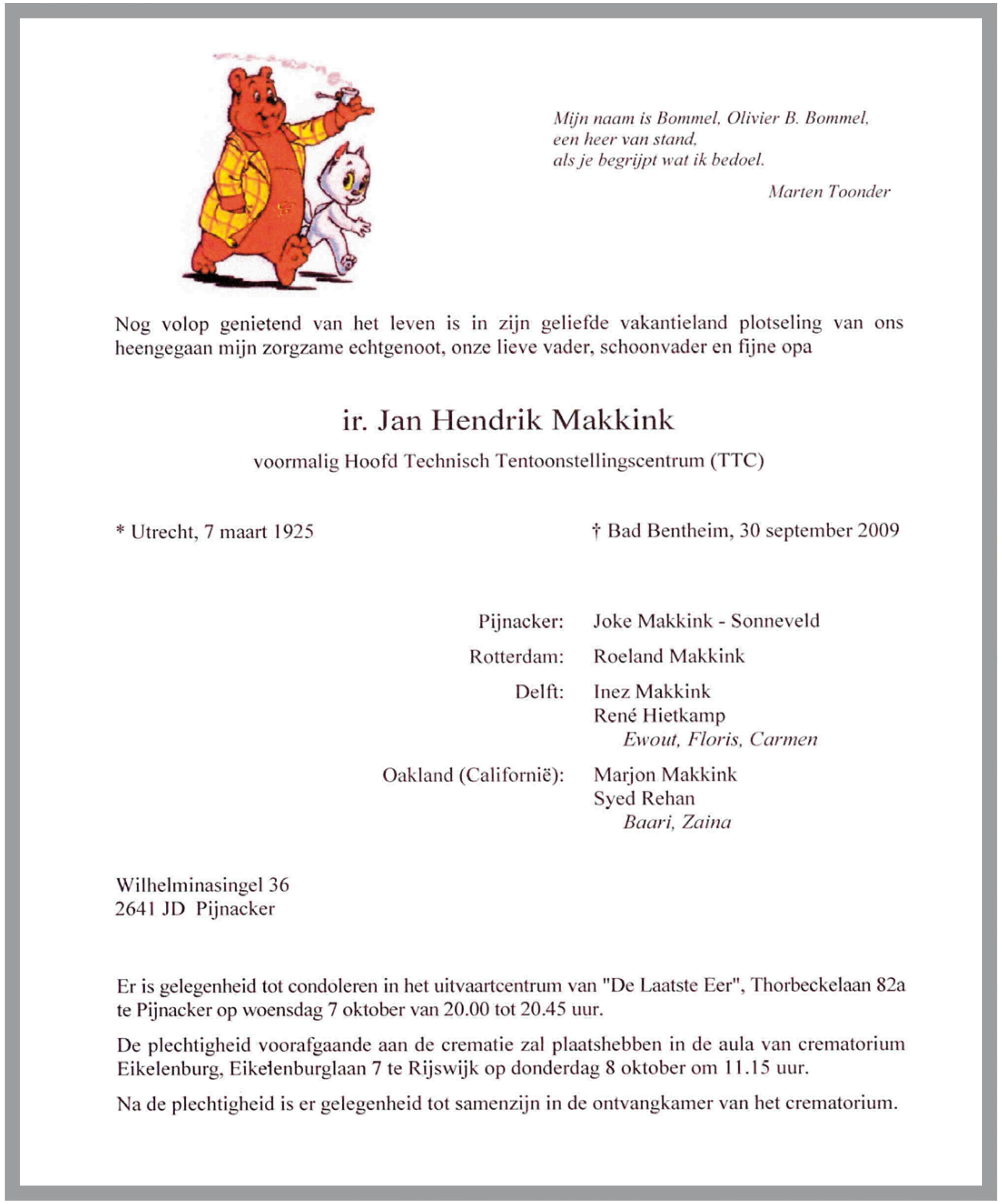
In memoriam

Ir. J.H. Makkink

Onlangs is op vierentachtig-jarige leeftijd ir. J.H. Makkink overleden. Jan Makking was één van de medeoprichters van de Nederlandse Vacuümvereniging NEVAC en was ook een bestuurslid van het eerste uur (1962). Voor het NEVACblad is het daarom gepast om bij het overlijden van Jan Makkink stil te staan en hebben wij ter herinnering het overlijdensbericht hieronder bijgevoegd.



Mijn naam is Bommel, Olivier B. Bommel,
een heer van stand,
als je begrijpt wat ik bedoel.
Marten Toonder

Nog volop genietend van het leven is in zijn geliefde vakantieland plotseling van ons heengegaan mijn zorgzame echtgenoot, onze lieve vader, schoonvader en fijne opa

ir. Jan Hendrik Makkink

voormalig Hoofd Technisch Tentoonstellingscentrum (TTC)

* Utrecht, 7 maart 1925 † Bad Bentheim, 30 september 2009

Pijnacker:	Joke Makkink - Sonneveld
Rotterdam:	Roeland Makkink
Delft:	Inez Makkink René Hietkamp *Ewout, Floris, Carmen*
Oakland (Californië):	Marjon Makkink Syed Rehan *Baari, Zaina*

Wilhelminasingel 36
2641 JD Pijnacker

Er is gelegenheid tot condoleren in het uitvaartcentrum van "De Laatste Eer", Thorbeckelaan 82a te Pijnacker op woensdag 7 oktober van 20.00 tot 20.45 uur.

De plechtigheid voorafgaande aan de crematie zal plaatshebben in de aula van crematorium Eikelenburg, Eikelenburglaan 7 te Rijswijk op donderdag 8 oktober om 11.15 uur.

Na de plechtigheid is er gelegenheid tot samenzijn in de ontvangkamer van het crematorium.

Agenda

18-23 October 2009

13th European Conference on Applications of Surface and Interface Analysis , Anatalya, Turkey

Voor meer informatie zie: http://www.allconferences.com/conferences/2008/20081014054832/

18-21 October 2009

23rd International Conference on Vacuum Web Coating'', Amelia Island, Florida, USA

Voor meer informatie zie: http://www.aimcal.org/association/ftcpapers.asp

8-13 November, 2009

AVS 56th International Symposium, San Jose, CA, USA

Voor meer informatie zie: http://www2.avs.org/symposium/AVS56/pages/info.html

30 november-4 december 2009

Materials Research Society Fall Meeting, , Boston, MA, USA,

Voor meer informatie zie: http://www.mrs.org/s_mrs/sec.asp?CID=9546&DID=198609

19-20 January 2010

FOM meeting 2010, Veldhoven, The Netherlands

Voor meer informatie zie: http://www.fom.nl/live/agenda/physicsatFOM/information.pag

10th-11th February 2010

1st Vacuum Symposium UK in conjunction with 9th RGA Users Meetings, Daresbury Laboratory, Warrington UK.

Voor meer informatie zie: http://www.astec.ac.uk/VS-1/

4-9 April 2009

Materials Research Society Spring Meeting, , San Francisco, CA, USA.

Voor meer informatie zie: http://www.mrs.org/s_mrs/index.asp

17-22 April 2010

2010 53rd SVC Annual Technical Conference, Orlando World Center Marriott Resort and Convention Center, Orlando, FL, USA.

Voor meer informatie zie: http://www.svc.org/ConferencesExhibits/Future-Meetings.cfm

Orgaan van de Nederlandse Vacuumvereniging

NEVAC *blad*