THE MIDAS EXPERIMENT FOR THE ROSETTA MISSION.

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ABSTRACT

The international Rosetta mission to comet Wirtanen will be launched by the European Space Agency in January 2003. The Micro-Imaging Dust Analysis System (MIDAS) is one of the key elements of Rosetta's scientific payload designed to collect dust particles drifting outwards from the cometary surface. MIDAS is based on an atomic force microscope (AFM), a type of scanning probe microscope able to image small structures in 3D at nanometer scale resolution. This instrument is a completely new development and will be the first application of atomic force microscopy in space science.

Principle of an Atomic Force Microscope (AFM).

An AFM belongs to the family of the Scanning Probe Microscopes. They all make use of a sharp tip scanning the surface of a sample and derive information from the tip-sample interaction. Using piezo-electric motion systems, the surface features can be resolved with atomic resolution yielding the topography and some additional material properties of the sample.

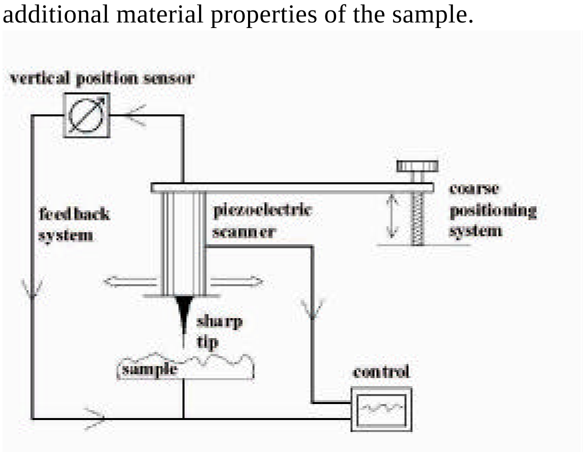

Fig. 1 Principle of an AFM

Figure 1 schematically shows the basic elements of an AFM. A piezoelectric scanner for cantilever movement, a tip near the edge of the cantilever, a detection system for cantilever deflection, a feedback system to control the vertical tip position and a computer to control the scanner and acquire and process the data. In addition, a coarse approach system for the tip is needed to bring it within working distance of the piezoelectric scanner.
The tip-sample interaction results from a combination of the short range, repulsive atomic force and the long-range van der Waals force. The contact between the tip and the sample occurs when the overall interaction force becomes repulsive. At the tip-sample distance of a few Å, both attractive and repulsive components cancel out and the interaction force becomes zero. According to the position of the working point of the AFM on the force-distance curve the mode of operation is called contact mode, non-contact mode, or tapping mode.
The Midas instrument will operate in the tapping mode. The tip movement over the surface must be reproducible, which can be achieved by piezo-electric position elements. The combination of the tip, supporting cantilever, and positioning element is called the XYZ scanner head. This allows us to make a three-dimensional image of a dust particle. Due to lifetime limits of the tips, several tips (16) will be mounted on the scanner for redundancy. (See figure 4) A few of them are coated with Cobalt to measure magnetic domains if they are present. The deflection of the cantilever is measured with a piezo-resistive Wheatstone bridge.
To be able to measure the height resolution of <10 nanometer the AFM must be mechanically isolated from the rest of the spacecraft to prevent mechanical noise from micro-vibrations induced by other mechanisms. For this reason the AFM-baseplate is mounted on 4 silicon rubber isolators. During the launch this baseplate is properly fixed with a clamping mechanism. After launch it will be released.

SCIENTIFIC REQUIREMENTS.

Lateral resolution: 4 nanometer
Height resolution: 1 nanometer
Max. scan field: 100 x 100 μm
Minimum scan field: 1 x 1 μm
Image size: typically 256 x 256 pixels

DESIGN REQUIREMENTS.

Total mass: 8000 grams (electronics 1850 gr. included)
Overall dimensions boxes:
L(with funnel)=236mm, D=216mm, H=276mm
Average power consumption: 12 Watt
Telemetry bit-rate: average 100 bps.
Global frequency >150 Hz.
Micro-vibrations: > 80 Hz, 0.0125 g.
Lifetime: > 10 years
Cleanliness: All assembly in class 100 environment.

Qualification vibration levels:

X-axis	4.0 grms
Y-axis	6.4 grms
Z-axis	9.7 grms

Temperature range: Operational: -20..+55 °C
Non-operational:-30..+60°C

Figure 2 shows the total instrument.
Figure 3 shows the AFM on the baseplate only.

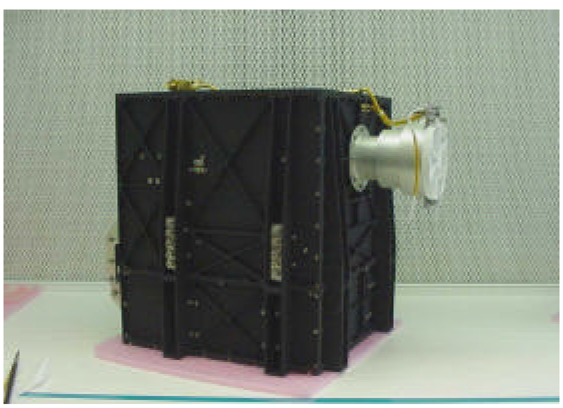

Fig. 2 The MIDAS instrument

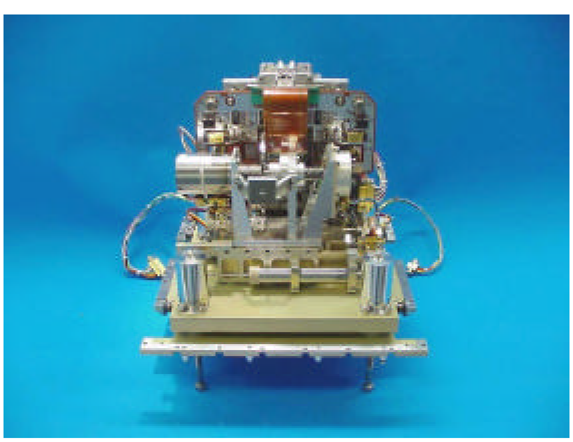

Fig. 3 The AFM only

The MIDAS instrument contains 7 different mechanisms. (see annex 1).

1. **Cover** to keep the funnel closed and clean in pre-launch and launch conditions. To be released with a Pyro-Piston Actuator.
2. **Shutter** to control deposition time of the dust flux on the target wheel. Operated by a Piezo-Electric motor.
3. **Wheel assembly** includes a Piezo Electric Motor motor and an Incremental Encoder.
4. **Translation stage** for tip selection, operated by a Piezo Electric Motor.
5. **Approach mechanism** for the coarse approach of the tips to the samples. Operated by a DC brush-motor in a hermetically sealed pressurised container.
6. **XYZ scanner** for three-dimensional scanning of the sample. Operates with three piezo-electric actuators. Two SMA's are implemented for launch-lock of the X and Y scanner.
7. **Clamping mechanism** (4x) to fix the AFM-baseplate before and during the launch. Two paraffin actuators release all 4 clamps.

PRINCIPLE OF OPERATION. (See annex 1)

The MIDAS instrument consists of 2 boxes, the AFM-box and the Electronic box. After integration the AFM-box is fixed on top of the Electronic box but during assembly it can be hinged in order to have access to the internal harness.
The electronic box contains mainly digital- and analogue electronics and the interfaces with the spacecraft. Also the AFM-box contains some electronics.
After the launch the following activities will be done:

1. Opening of the cover in front of the funnel.
2. Release of the clamping mechanism of the baseplate.
3. Release of the launch-lock mechanism of the XYZ stage.
4. Release of the 'Approach launch-lock"
5. Release of the Translation Stage from the launch lock position.

After 8 years of travelling the spacecraft will enter the vicinity of the comet and the dust-particles can enter the AFM through the funnel. Between the shutter and the collection area of the wheel a collimator/baffle limits the dust flux cross section to the size of a chip (1.5x2mm).
The encoder that is connected to the shaft of the wheel indicates which chip is exposed.
After a variable exposure time the wheel will turn 180 º and brings the exposed chip in front of one of the 16 needles on the scanner head. The approach mechanism will bring the needle in contact with the sample and the scanning can start.
If one of the needles is worn out the translation stage can position the wheel in front of another needle. The condition of a tip can be checked with one of the calibration chips.

Figure 4 shows the array with 16 cantilevers, the flexible cable and 2 piezo elements for the dynamic mode.
Both the position of the translation stage and the approach distance of the cantilevers to the wheel are measured with a Linear Variable Differential Transformer (LVDT).

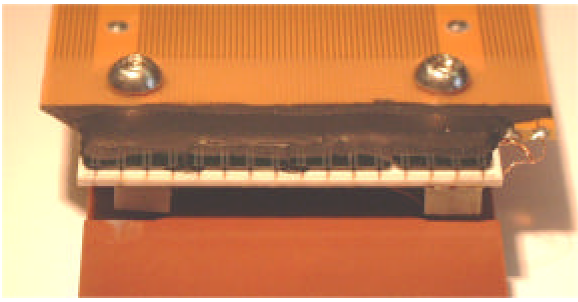

Figure 4 The array with 16 cantilevers

DESCRIPTION OF THE ABOVE MENTIONED MECHANISMS.

Cover

The cover is shown in annex 1 in both open and closed position and is mounted in front of the funnel.
The opening is done by releasing a latch-mechanism with a redundant pyro-piston actuator.

Shutter

The shutter is mounted at the inside end of the funnel. A cylinder with two thoroughfares rotates in another cylinder with two thoroughfares by means of a piezo-electric motor. The open- and close positions are determined by micro-switches.
Figure 5 shows a photo of the shutter with motor and switches as it is designed by Multin company.

Fig. 5 The shutter of the dust-intake system

Clamping mechanism

As micro-vibrations induced by other mechanisms on board of the spacecraft could effect the quality of a high resolution scan the AFM module is mounted with four silicon rubber isolators on the AFM-Box baseplate. (see annex 1)
Before and during the launch the AFM module must be firmly fixed to the box. This is done with four clamps. After release of the clamps any metal contact of the AFM module with the box is not tolerated to avoid coupling of micro-vibrations induced by other mechanisms on board of the spacecraft.

Principal of operation:

Fig.6 Shows the principle of the clamping mechanism

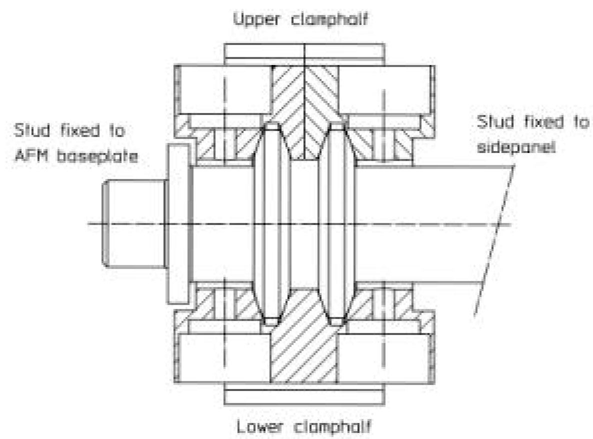

Fig. 6 Principle of the clamping mechanism

One set of clamps (one upper and one lower) firmly connects a stud of the AFM-baseplate with the stud which is fixed on a side panel of the AFM-box. The clamps are closed with a lever. The clamping force can be adjusted by set-screws in the lever and controlled by integrated strain-gages. The pre-load for each clamp is 880 N. The release happens when the lever is pushed away by a paraffin actuator. Consequently both upper and lower clamp-half separate from the stud due to an build-in push-pin and a blade spring which is fixed on the rear side of the clamp. Several adjustments are foreseen in the mechanism to obtain a proper alignment of the studs with respect to the clamps. Each set of clamps and studs are matched pairs.

Fig. 7 Shows one set of clamps with a Starsys Reserach paraffin actuator and microswitch as it is designed by MULTIN company.

As the levers of the two clamps on the same panel are connected with a steel cable, one paraffin actuator releases both, but one after the other because the fixation of the cable to the second clamp is closer to the hinge.

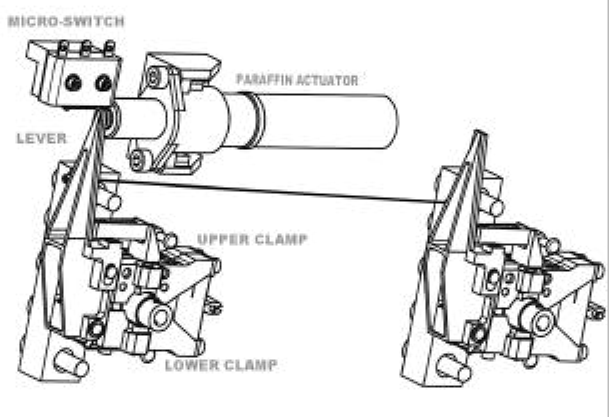

Fig. 7 One set of clamps

XYZ scanner

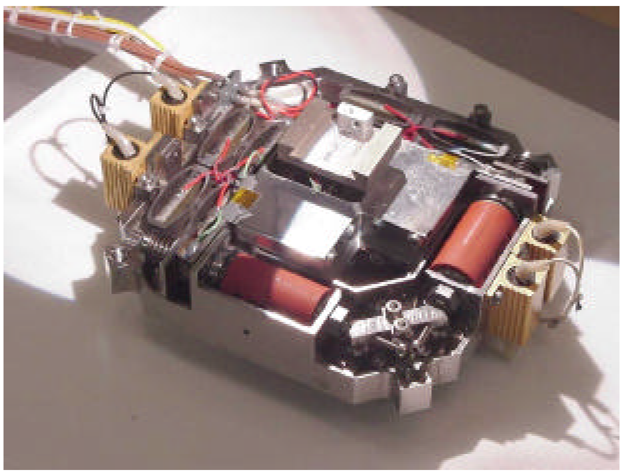

Fig. 8 The XYZ scanner. The 2 round cylinders are the SMA actuators.

The stage is locked for the launch with SMA actuators. Latch status indicators show the release after activation.
Characteristics of the XYZ stage
Stroke X: 100 µm
Stroke Y: 100 µm
Stroke Z: 10 µm
Displacement measured with capacitive sensors.
Design loads: 40 grms max.
A full description of the XYZ stage is given in paper with reference 2.

Figure 8 shows the front view of the stage.

Wheel assembly.

The circumference of the wheel has 64 facets. Four of these facets are provided with calibration gratings. Two of these are used to calibrate the X, Y and Z stroke of the scanner-head, one to calibrate the position of the chips with respect to the cantilevers and one to make an image of the condition of the needles on the cantilevers. The remaining 60 facets are covered with chips of silicon. These chips are coated with Sol Gel to provide a good adhesion of the incoming dust particles.

Fig.9 shows the wheel assembly.
Fig.10 a detail of the facets.

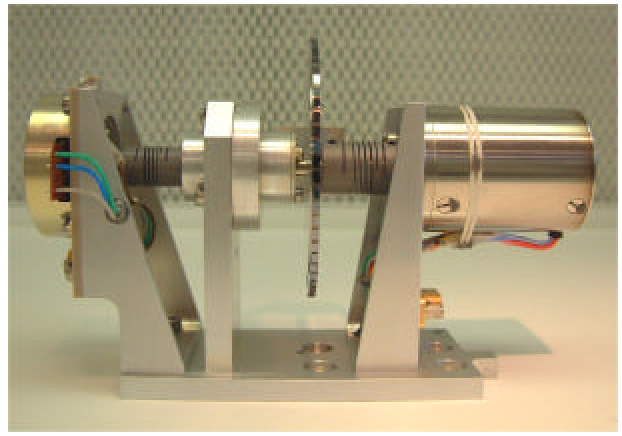

Fig. 9 Wheel assembly

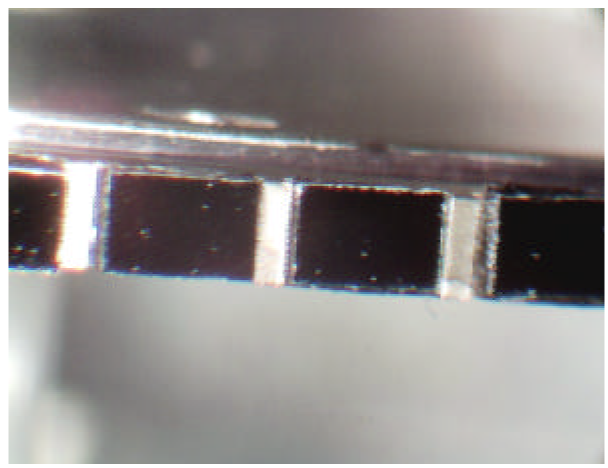

Fig. 10 Detail of 2 facets with silicon oxide chips

<u>Technical details of the wheel assembly</u>:

Total mass: 290 grams
Angular contact ball bearings type RMB RA4012X, matched pair.
Vibration loads: axial: 72 grms. (3 S)
Radial: 90 grms. (3 S)
Design loads: Axial: 81 N
Radial: 70 N.
Bearing preload: 30 N.
Preload: 30N
Drive: Piezo electric ultrasonic motor.
Max. required spindle torque: 0.005Nm

Lubrication of ball bearings: Lead ion plated by and lubricated with Braycote 601 by ESTL.

Encoder:
Codechamps incremental encoder
Resolution: 1024 peroides
Channels: 2 channels + zero index.
Mass: 80 grams.

Translation Stage.

Principle of operation:
A spindle driven by a piezo-motor moves the platform. On top of the platform the wheel assembly is mounted. At the two ends of the stroke a micro-switch stops the motor. The displacement is measured with an LVDT. At one end of the stroke the platform can be put in the launch-lock position.
Fig. 11 shows the translation stage with the LVDT. The coil of the LVDT is fixed on the frame of the translation stage and the core on the platform.
The position accuracy is 5 um.

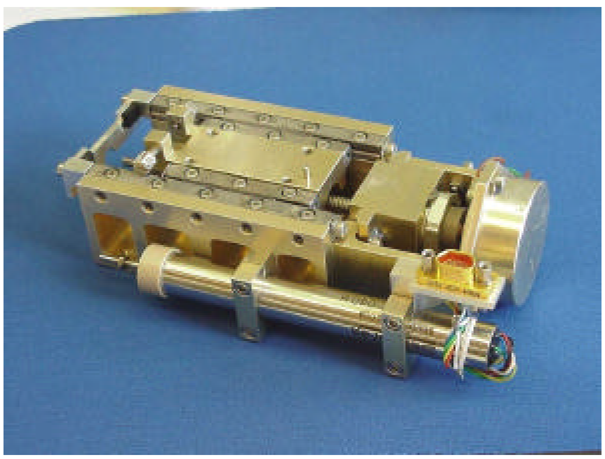

Fig. 11 The translation stage with LVDT

<u>Technical details of the translation stage:</u>
Stroke: 32mm
Mass: 370 grams
Max. required spindle torque: 0.012Nm at - 20°C

Linear actuation by:
Recirculating hard-preloaded ballscrew (Steinmeyer 1214/1/5/90/110T3P).
Vibration loads: Axial 59.1 grms (3 S)
Design loads: axial 213 N
Preload: 60N

Angular contact bearings (matched pair):RMB:RA4160X.
Vibration loads: Axial 59.1 grms (3 S)
Design loads: axial 213 N
Preload: 60 N

Linear bearings:
Schneeberger:R2045-RF and R2075-R (7 x AC2)
Radial: 88.5 grms (3 S)
Design loads: radial 400N
Preload: 260N

Lubrication of both ball- and linear bearings by ESTEL with lead ion plating and Braycote 601.
Stroke end-switches: Honeywell microswitch 1MT1
Interface Piezomotor – translation stage: ALN T180. (Electrical insulated for EMC reasons, good heat conductivity).
Drive: Shinsei Piezo electric ultrasonic motor.

Launch-Lock device of the translation stage.
(See fig. 12.)
Before launch the platform of the translation stage is put in the launch lock position.
In this position a conical pin is inserted with a certain pre-load into a plate made of Peek.
Due to the high holding torque of the piezo-motor the spindle is self-braking and the pre-load will be maintain during the launch vibration.
After launch the lock will easily release as soon as the piezo-motor is started.

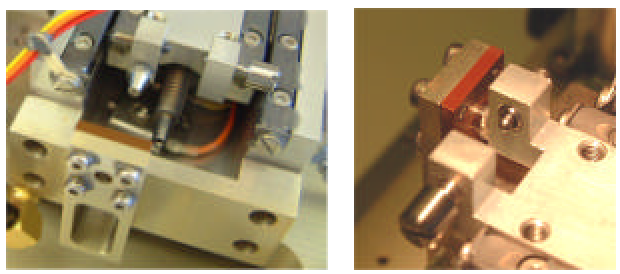

Fig. 12 The launch-Lock elements in open and locked position.

Approach mechanism.

The approach mechanism is used to make an approach of a needle to the sample on the wheel.

Principle of operation. (See fig.13)
A set of bearings on top of the approach mechanism separates the two parts of a wedge when it expands or brings them together when it shortens.
One half of the wedge is mounted on a stiff pillar and the second half on the XYZ-stage. The XYZ stage hinges on two flexures. The stroke is limited by two micro-switches and measured with a LVDT.

With a reduction ratio of 1:1000 of the gearbox, a spindle with a pitch of 0.5mm and a ratio of 1:4 with the wedge, one turn of the DC motor gives a displacement of 125 nanometer of the needle of the cantilever.
The 2 halves of the wedge stay in contact with the bearings by means of 2 extension springs. .

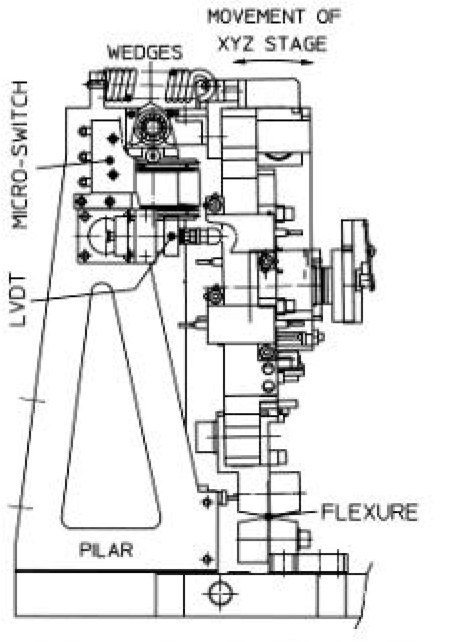

Fig. 13 XYZ stage with approach

The approach mechanism itself consists of a brush-DC motor with a gearbox and a threaded spindle. All these parts are mounted in a hermetic sealed container (helium leakrate < E-9 mbarl/sec) with an edge-welded bellow on one end. The total stroke is 4.2mm.

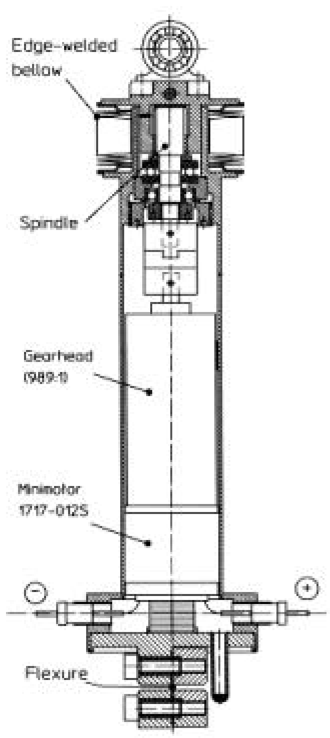

Fig. 14 Cross section of the approach mechanism

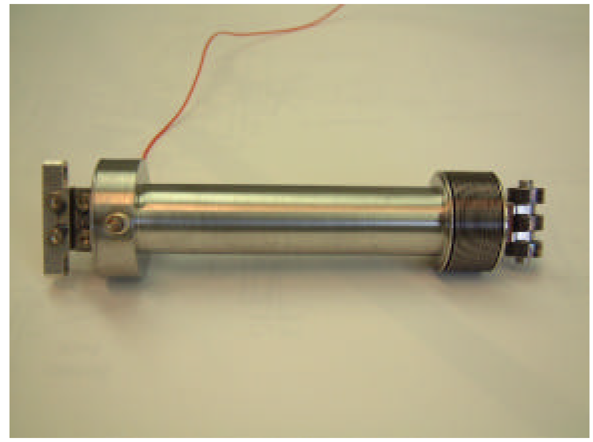

Fig. 15 The approach mechanism

Before and during the launch the approach cylinder is lengthened until two blocks of Peek which are mounted below the bearings come between the wedges. In this configuration the bearings are off-loaded. The extension springs pull the XYZ stage with a force of 328N against the pilar.
During launch-lock release the DC-motor shortens the approach until the bearings contact the wedges again.

Figure 14 shows the cross-section of the approach mechanism.
Figure 15 shows a photograph of the approach mechanism.

<u>Technical details of the approach mechanism:</u>
Mass 175 grams.
Bearings type:
Radial support bearing: RMB ULK409X
Axial bearing: RMB B410
Wedge bearings: RMB RX410X

Vibration loads: 75 grms (3 S)
Design loads: Axial 30 N.
Radial 49 N.
Preloads: Radial: none
Axial: 10 N

Motor for the translation stage, wheel assembly and shutter.

For the transport of one and rotation of two mechanisms a piezo-electric motor is used.
As the mechanisms should never work simultaneously there is only one electronic driver which can be swapped between the three.
The very high holding torque of the motor is very much in the benefit of both the wheel drive and the translation stage. For the first because the wheel is blocked during a scan and the latter because the translation stage is self-locking during launch.

The very good mass-torque ratio saved a lot of mass in the design of the instrument.
The motor has been qualified for the vibration levels and temperatures which were specified for the MIDAS experiment.
Fig. 16 shows a photograph of the motor.

Fig. 16 Piezo electric motor**.**

<u>Technical details of the piezo electric traveling wave motor.</u>
Make: Shinsei
Type: USR30-B3
Driving frequency: 50 KHz
Drive voltage: 110 Vrms
Rated torque: 0.05 Nm
Max. Torque: 0.1 Nm
Holding torque: 0.1 Nm
Rated speed: 250 rpm.
Direction of rotation: CW, CCW
Operating temp. –20 °C + 60 °C
Limit of continuous operation: 2000 hours
Dimensions: diameter 30 mm, total length 25mm, shaft diameter 4mm, shaft length 14mm.
Weight: 20 grams.
Bearing: Lubricated by ESTL with lead ion plating and Braycote 601.

Mission requirements for the motor:
Max. total operation time of the translation-stage: 4 hours
Max. total operation time shutter: 2 hours
Max. total operation time wheel: 10 hours
Operating temp. –20 °C + 60 °C
As the propulsion of the motor is based on friction the vacuum working environment could increase the failure of the motor because of overheating of the friction material.

Extensive test in vacuum have learned the following:

1. A good heat conductivity from the stator to the environment is needed.
2. Torque load < 0.05 Nm
3. Stator temperature < 70°C
4. Operation time < 2000 hours

For accurate positioning of the wheel and the translation stage the motor was operated in a pulse mode with duty cycles from 50% (1msec ON, 1 msec OFF) and lower

Present situation and the first results.

The instrument is fully qualified on vibration, shock, thermal vacuum and EMC levels.
A scan-test under micro-vibration conditions and the AFM mass off-loaded for gravity is planned for autumn 2001.
Figure 17 shows the first image. This was made under vacuum condition and at a temperature of 40 °C. It is an image of a height-calibration chip of 105 nanometer which is mounted on one of the facets of the wheel.

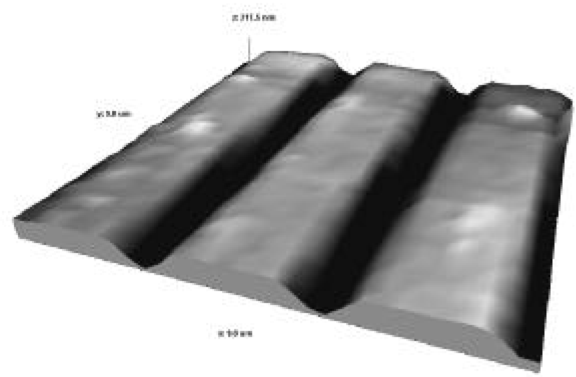

Fig. 17 First image of the height calibration chip

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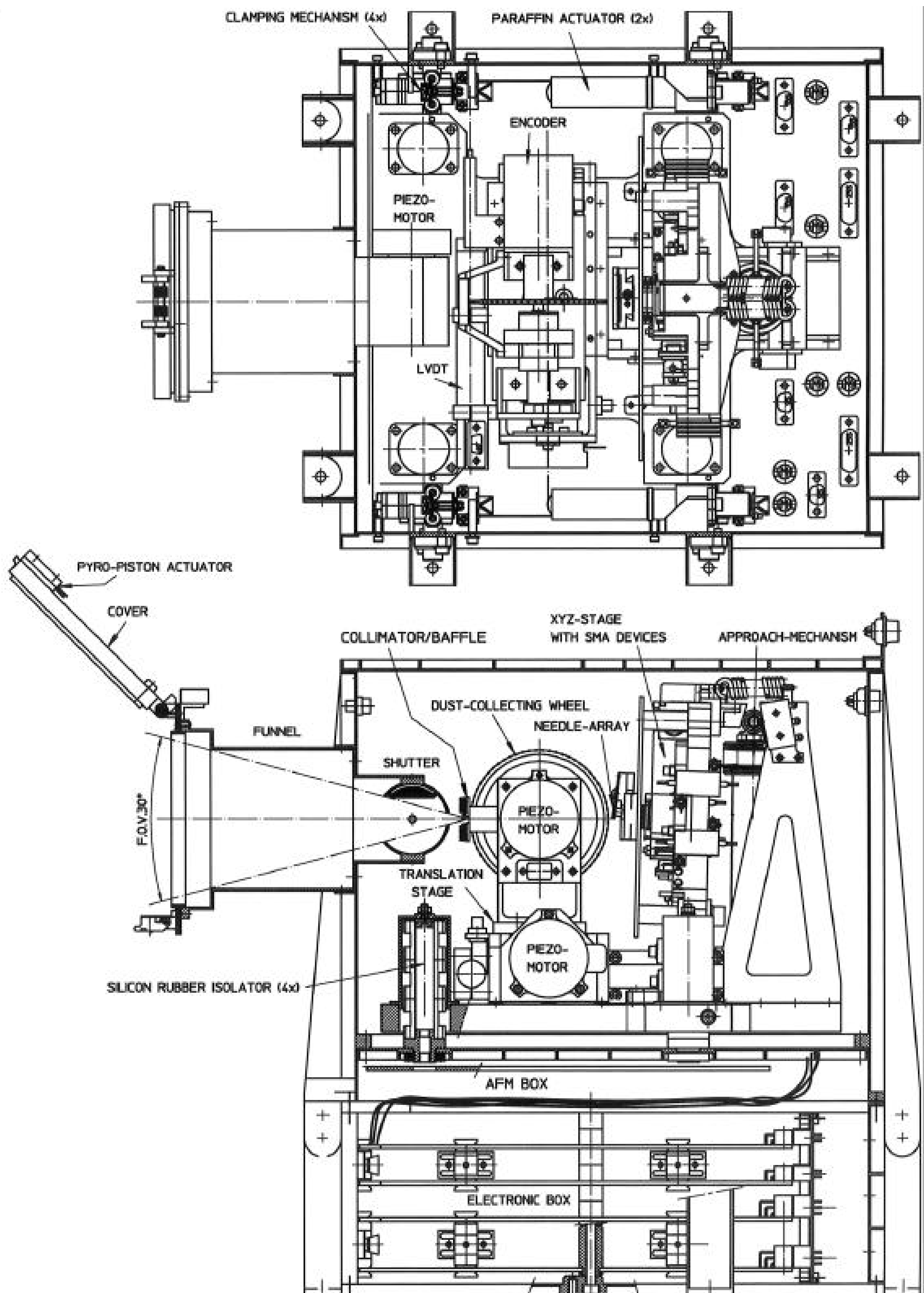

Annex 1. Top-view and cross section of the MIDAS instrument