attoMOTION

Ultra-Precise Nanopositioning Devices

User Manual – Premium Line

Positioners & Scanners

attocube systems
Eglfinger Weg 2
D - 85540 Haar, Germany
www.attocube.com

For technical queries, contact:
support@attocube.com

attocube
pioneers of precision

Version:	2.2
Modified:	December 18
Products:	ANP – linear positioners ANR - rotators ANG - goniometers ANS - scanners
Readout:	open loop closed loop: /RES closed loop: /NUM
Environments:	ambient: /RT vacuum: /HV, /UHV cryogenic temperatures: /LT, /LT/HV, /LT/UHV

Overview

The great success of attocube's positioners is based on the unique combination of a patented driving technology, the powerful design, the selection of high quality material, and the extensive experience of the attocube staff. The Premium Line of linear, rotary, and goniometer-like positioners and scanners offers the opportunity to realize new experimental possibilities. The patented driving technology plays an important role in achieving a variety of applications. Depending on the requirements, one can choose from different sizes, travel ranges, and direction of movement.

Our positioners allow reliable movement over centimeter ranges with nanometer precision under a large variety of conditions such as low temperature, high magnetic fields, or ultra high vacuum. Many of the positioners can be equipped with a position sensor for closed loop operation with nm-resolution. By assembling several stages, one can obtain positioning units with up to six degrees of freedeom.

Extreme Environments

The ANP product line meets the challenge of nanoprecise, commercially available positioning systems working reliably under extreme environmental conditions. Suitable models are available for cryogenic temperatures, high and ultra high vacuum as well as high magnetic fields.

Large Travel Ranges in Extreme Environments

Positioners of the Premium Line take advantage of attocube's patented inertial drive technology which is dedicated for use in extreme working environments. Controllable motion over millimeter ranges with small and reproducible steps can also be achieved in cryogenic environments, where PZT piezo ceramics are usually limited to scanning ranges of only a few microns.

Closed Loop Control

Exact and repeatable positioning in absolute and relative terms is an easy task for all ANP positioner models with integrated encoders. For this product line two different encoder types (/RES and /NUM) are available and are already directly integrated into the positioner.

Multi-Axis Operation

attocube's ANP positioners are available in a wide variety of designs, sizes, and travel ranges and can be stacked directly on top of each other for multi-axis operation.

Safety information

For the protection of the equipment, the operator should take note of the **Warnings, Cautions,** and **Notes** throughout this handbook.
The following safety symbols may be used throughout the handbook:

Warning. An instruction which draws attention to the risk of injury or death.

Caution. An instruction which draws attention to the risks of damage to the product, process, or surroundings.

Note. Clarification of an instruction or additional information.

Important warnings – read this section first!

Never connect the high voltage connector when any cabling contacts are exposed! The piezos at the heart of the positioner unit are high voltage components. These voltages can cause serious injuries.

Connect the positioning system to the protective earth system, or install it inside a cover preventing access to operator.

Switch the electronics to GND mode during cooling down or warming up the system.
During temperature changes, piezos may change their length and therefore, charges may accumulate. To avoid static charges that might damage the positioner, we suggest connecting the cabling to the controller, which is either in GND mode or switched off.

Never attempt to drive the positioner in a wet atmosphere.
Never connect voltages to the positioner when there is the possibility of condensation (water or ice) on the positioner or any part of it, e.g. when the positioner is colder than room temperature and in normal atmosphere. Be sure not to have any leakage in your cryogenic equipment as this can cause ice layers on the positioner.
Ion currents cause leakage paths in the piezos, which may permanently damage the piezos.

Never attempt to clean the positioners by immersing them into any liquid.
The piezo elements are sensitive to any kind of liquid. Ion currents can cause leakage paths in the piezo damaging it irrevocably.
Please note that the parts of the attocube positioners are cleaned in our production facility. If you have a contamination of the surface, please clean the positioner only as follows:

- In case there are dust particles on the surface, please use dust and oil free air to blow it off.
- In the rare event of dirt on the surface, please use a dust-free tissue or a cotton swab slightly tinctured with Isopropanol or Acetone to clean the surface. Please clean only the metallic parts of the surface, otherwise the lubrication of the guiding rod or the glued parts may be damaged. Please make sure that no droplets of solvent get into contact with the guiding rod, the piezo, or the glued parts of the positioner.

Do not use any grease to lubricate the guiding rod.
The travel mechanism of the positioners relies on friction and this friction is precisely adjusted by attocube's engineers. Any change of this friction may prevent the positioner from working. If you use vacuum grease in your setup, please take care that no grease is dropped onto the positioner or can reach the guiding rod by capillary forces.

Never apply any torque to the scanner when mounting it.
Always hold exactly the plate in which a screw is inserted. E.g. If one holds the bottom of the xy-scanner and mounts something on top of it, then both piezos experience from an uncontrolled torque!

Avoid shocks when working with scanners.
Avoid working on a hard workbench. Always use some foam or a pad to dampen the shocks when accidentally putting the scanner down. Avoid shocks to the flange or your holding construction when inserting the scanner into a vacuum chamber or a cryostat. Also, avoid having big loads and excessive vibrations at the same time.

Note: attocube takes no responsibility for breakdowns of the ceramic piezo stacks. In case of breakage, please contact attocube's support department for details of the repair service.

Table of Contents

I. Working principle

The great success of attocube's positioners is based on the unique combination of a patented driving technology, the powerful design, the selection of high-quality materials, and the extensive experience of attocube's staff.

I.1. Stepper positioner technology (ANP, ANR & ANG)

All attocube positioners qualified as ANP (linear positioners), ANR (rotators), or ANG (goniometers) stages use the slip-stick driving mechanism to translate the table over large distances (e.g. centimeter range in case of the ANP models) with atomic precision under a large variety of conditions such as low temperature, high magnetic fields, and ultra high vacuum.

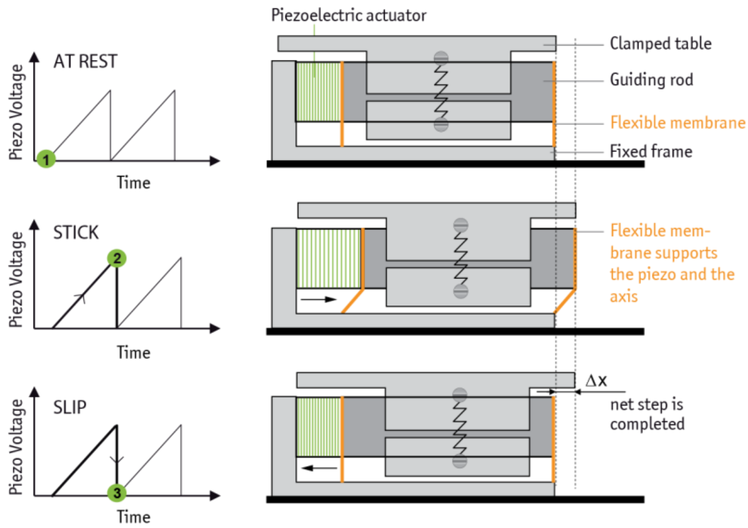


Figure 1*: The slip-stick drive principle:*
1. Sticking phase of the clamped table causing a net step
2. Acceleration of the guiding rod
3. Disengagement of the clamped table

Figure 1 shows the schematics of this driving mechanism based on applying sawtooth voltage pulses to the piezo:

1. A guiding rod is firmly connected to a piezoelectric actuator while the moving table is clamped to it. A sawtooth shaped voltage pulse is applied to the piezo.
2. During the phase of the slow flank the clamped table sticks to the guiding rod and is moved over a distance Δx. The higher the applied maximum voltage, the larger is the achieved expansion Δx. The typical minimum step size for ANP positioners is in the range of 50 nm at ambient conditions and 10 nm at cryogenic temperatures.
3. By applying the steep flank of the voltage pulse to the piezo, the guiding rod is accelerated rapidly over a short period of time so that the inertia of the clamped table overcomes friction. This way, the clamped table disengages from the accelerated rod and remains nearly stationary. The net step Δx is now completed.

The sum of several of these steps allows a theoretically infinite workspace which can be addressed with very high resolution.
The step size is typically a linear function of the applied voltage (beginning at a

minimum start voltage), and is only slightly dependent on the stepping frequency. The step size also depends on the clamping force settings and the applied load.

Please note that the onset of motion is not at 0 V, but at a certain threshold voltage. Additional measurements show that at a given frequency and applied voltage, the step size repeatability is typically better than 5 %. At the onset of the motion, this asymmetry might be higher. The step size in forward motion is usually larger than in backward motion.

As the positioners' operating principle is based on friction, attocube cannot guarantee any certain step size at a given voltage and frequency. Please refer to the specification sheet for a typical step size range at a given temperature and environment.

Step sizes may vary from one positioner to the other.

The main advantages of this driving mechanism are:

1. Grounding of positioners:
   When a position is reached after a series of steps, zero voltage is applied to the piezo. Therefore, there is no noise and no drift caused by any external electronics.

2. Low voltages:
   Only low to moderate voltages are needed to drive the positioners. In attocube's positioners, piezos with maximum 60V or 150V are used.

Finepositioning mode:
As DC voltages can also be applied to the piezos in the positioners (hereafter referred to as "fine positioning"), the devices function as both coarse stepper and fine positioner at the same time. This is a tremendous advantage in terms of compactness and stability of the setup as well as resolution in the nanometer range which is determined exclusively by the actuator itself and the electric circuitry for the piezos.

I.2. Scanner technology (ANS)

In contrast to the previously described coarse positioners, attocube's open loop ANS scanners are driven by applying DC voltages to their piezos. Typically, the ANS scanners are used in all applications where fine scanning over several tens of microns are required (e.g. microscope setups). ANS scanners are available either as a one-dimensional z-unit, a combined two-dimensional xy-unit, or as a three-dimensional xyz-unit.

All standard scanner units are made from high purity titanium with integrated flexure structures. By applying unipolar DC voltages to the integrated piezo elements the piezo itself is expanded and its motion is amplified by the titanium frame. Therefore, the scan range is heavily dependent on temperature.

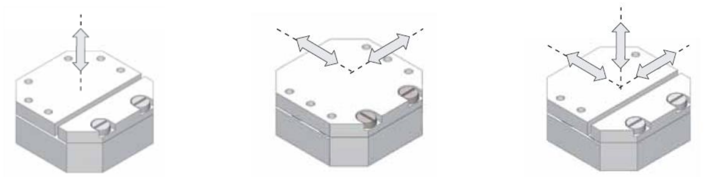


Figure 2: *ANS scanner models; ANSz100 (left), ANSxy100(middle), ANSxyz100 (right)*

Temperature dependency:
The piezo electric effect and therefore the achievable scan range is temperature dependent. The maximum scan range of a piezo reduces with temperature. A temperature change from standard ambient conditions down to liquid helium temperatures (4K) typically results in a reduction of the scan range by a factor 3-5.

Hysteresis:
As all ANS scanners are open loop models, hysteresis plays an important role for all applications, especially microscope measurements.
Hysteresis is a piezo inherent feature resulting from saturation effects of the piezo and its ferroelectric properties. It is a function of applied voltages and also the amplification of the scanner frame. Typical hysteresis data is in the range of 5-15% of the maximum scan range (see Figure 3).

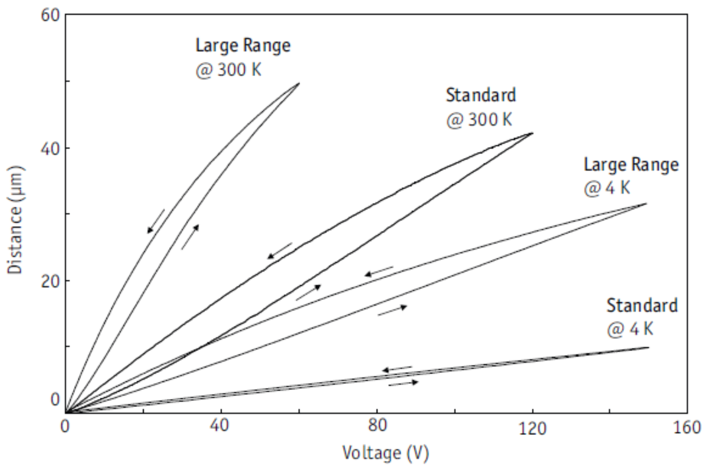


Figure 3: *Hysteresis curves of different ANSxy100 scanners*

II.General handling of attocube's positioners & scanners

attocubes's positioners and scanners are quite modular. A typical combination is an ANPxyz101 coarse positioning stack with a scanner mounted on top. This is realized by first mounting two ANPx101 stages with perpendicular orientation on top of an ANPz101. This way, xyz-coarse positioning is achieved (see Figure 4). The scanner unit can then be mounted on top of this stack.
The complete positioning unit can be mounted onto a base flange or into any setup.

The rules and hints given for this type of positioner set are also applicable for other positioner combinations!

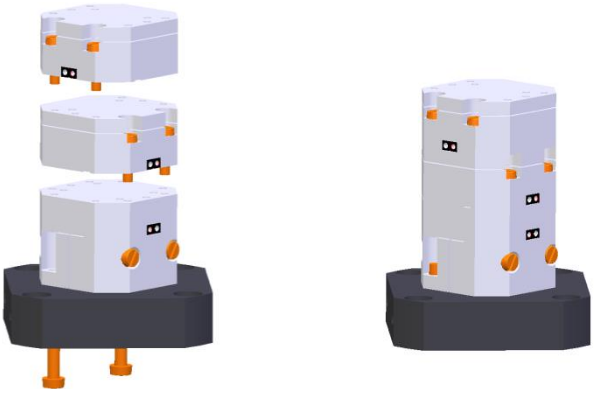


Figure 4: *A typical xyz positioning system consisting of two ANPx101 mounted perpendicular on top of each other and one ANPz101 positioner model. The assembly is mounted onto a base flange.*

Each guiding rod of the positioner and scanner is based on a piezoelectric ceramic stack drive element. The x- and z-positioners are delivered mechanically separated from each other to ensure that the ceramic piezoelectric actuators are not damaged during shipping.

The piezoelectric stack elements are unipolar and can only be used in the specified range of positive voltages. Please refer to the specification sheets delivered with the positioners and scanners.

II.1. Unpacking

Generally, attocube's positioning units are delivered unmounted in a box and can be stacked together to achieve a multidimensional positioning unit.

In accordance to different types of positioners we also offer appropriate electronic control units. As a standard we deliver suitable positioner control cables as well as a USB cable and mains cable with all controllers.

Although the integrated piezo ceramics are secured in the titanium frame of the positioners and scanners, they are quite brittle and are therefore sensitive to mechanical shocks. Please work on a soft foam plate or a similar shock-absorbing pad underlying when handling the positioners and scanners. This helps to avoid damage and breakage in case the positioner is accidentally dropped!

All positioners are adjusted and tested by attocube's engineers according to their specified environment. It is therefore of prime importance that all setscrews are leaved untouched by the user (see Figure 5) as otherwise the nanopositioning item is no longer under warranty!

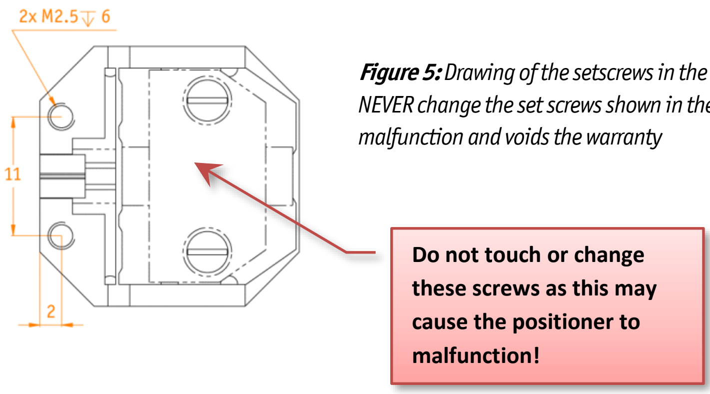


Figure 5: *Drawing of the setscrews in the bottom flange of the ANPx101 positioner. Please NEVER change the set screws shown in the picture as this may cause the positioner to malfunction and voids the warranty*

It is strongly recommended to mount all attocube positioners onto a fixed base plate to achieve best possible performance of the positioners.

II.2. Mounting on a base plate

Each attocube positioner must be mounted to a fixed base or base plate to ensure reliable functioning and an optimized performance. All attocube nanopositioner toolbox sets include suitable base plates which can be used for testing purposes.
Whereas mounting from the bottom side is possible for all positioner models, direct mounting from the top is possible only for some models. Therefore, if mounting from bottom is not possible, suitable adapter plates can be ordered separately.
The following sections II.3 and II.4 include lists of suitable screws needed for mounting the positioners from top and from bottom as

well as mounting samples on top of the positioners for all available positioner models.

As an example, Figure 6 shows how an ANPz101 positioner can be mounted from bottom to a base plate. According to the respective table in section II.3 M2.5 screws are needed. The maximum length of a screw which is mounted directly into the positioner is 6 mm (M2.5 x 6). Depending on the thickness of the base plate the used screw can be longer, e.g. M2.5 x 10.

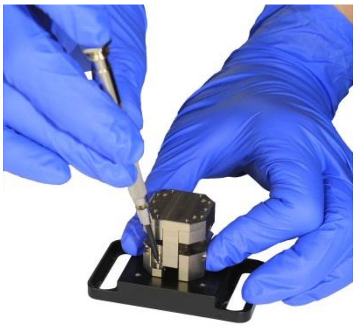


Figure 6: *Mounting the positioner onto a base plate. The positioner is to be attached from the backside of the base plate using two M2.5 screws.*

Please refer to the specification sheet for the exact mounting pattern of your positioner!

II.3. Mounting: ANP, ANG, ANR coarse positioners

ANP – Linear Positioners

As described before, an ANPxyz101 system is built with two ANPx101 positioners and one ANPz101 positioner mounted on top of each other to establish the 3D-positioning unit (see Figure 4).

The first step of assembling the xyz positioner is to mount one of the x-positioners on top of the z-positioner using two M2x8 screws. The part which contains the thread should always be hold while mounting to avoid torque on the piezo elements.

In a next step, the second x-positioner is mounted in perpendicular orientation on top of the xz-positioning unit using a second set of M2x8 screws (see Figure 7). Though the positioners have integrated membranes stabilizing the piezo and are therefore very rugged, try to avoid using excessive force while mounting your setup.

Figure 7: *Mounting of the y-axis onto the z-axis. The base plate of the upper positioner should be held firmly while mounting.*

The above mentioned general mounting instructions are valid for all linear positioner models. Please refer to the specifications sheets regarding specific screw size and maximum allowable screw length, as screws that exceed this length may damage the positioner. Suitable screws for the respective positioners are listed below and are part of the nanopositioning toolbox which can be purchased separately:

Model	Mounting from top		Mounting from bottom		Sample mounting	
	Qty	Screws	Qty	Screws	Qty	Screws
ANPz30	---	---	2	M2 x 3	2	M1.6 x 2
ANPx51	2	M1.6 x 4	2	M2 x 5	2	M1.6 x 2
ANPz51	---	---	2	M2 x 5	2	M1.6 x 2
ANPx101	2	M2 x 8	2	M2.5 x 6	2	M2 x 3
ANPz101	2	M2 x 8	2	M2.5 x 6	2	M2 x 3
ANPx311	4	M2 x 8	4	M2.5 x 6	4	M2 x 2.5
ANPx321	4	M2 x 8	4	M2.5 x 6	4	M2 x 3
ANPx341	4	M2 x 8	4	M2.5 x 6	4	M2 x 3

ANG – Goniometers

Generally, an “ANGt” type goniometer is intended to be mounted with perpendicular orientation on top of an “ANGp” type goniometer so that both positioners offer the same center of rotation and -positioning around one point is achieved (see Figure 8).

Figure 8: *Schematics on the center of rotation of two combined goniometers.*

The goniometers can be mounted on top of each other according to the previously mentioned mounting instructions for linear positioners. Please refer to the specifications sheets regarding specific screw size and maximum allowable screw length as screws that exceed this length mayt damage the positioner. Suitable screws for the respective goniometers are listed below and are part of the nanopositioning toolbox which can be purchased separately:

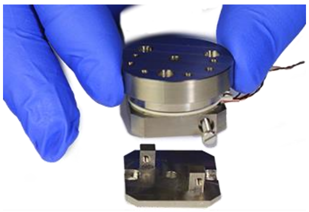
Model	Mounting from top		Mounting from bottom		Sample mounting	
	Qty	Screws	Qty	Screws	Qty	Screws
ANG50	2	M1.6 x 4	2	M2 x 3	2	M1.6 x 4
ANG101	2	M2 x 8	2	M2.5 x 6	2	M2 x 5

ANR - Rotators

Depending on the rotator type the mounting can either be done from the bottom, from the top or in combination with an adapter plate.

a) **ANR31**
This rotator can only be mounted from the bottom with two M1.6 screws.

b) **ANR51**
This rotator can only be mounted from the bottom with two M2 screws.



c) **ANR101**
This rotator can either be mounted from the bottom with two M2.5 screws or from top via the integrated adapter plate which is screwed to the side of the rotator with two M2 x5 screws. Fix the adapter plate to a base plate or another positioner with two M2 screws and fix the rotator again to the adapter plate.

d) **ANR240**
This rotator can either be mounted with vertical rotational axis (from the top with M2 screws, from the bottom with M2.5 screws) or with horizontal rotational axis with two M2.5 screws.

e) **ANRv51, ANRv220**
These rotator types can only be mounted from the bottom with two M2 or M2.5 screws, respectively.

Please refer to the specifications sheets regarding specific screw size and maximum allowable screw length as screws that exceed this length may damage the positioner. Suitable screws for the respective rotators are listed below and are part of the nanopositioning toolbox which can be purchased separately:

Model	Mounting from top		Mounting from bottom		Sample mounting	
	Qty	Screws	Qty	Screws	Qty	Screws
ANR31	---	---	2	M1.6 x 4	2	M1.6 x 1
ANR51	---	---	2	M2 x 2	2	M1.6 x 1
ANRv51	---	---	2	M2 x 3	2	M1.6 x 1
ANR101	2	M2 x 3	2	M2.5 x 5	2	M2 x 3
ANRv101	---	---	2	M2.5 x 4	2	M2 x 3
ANRv220	---	---	2	M2 x 4	2	M2 x 2
ANR240	2	M2 x 15	2	M2.5 x 5	2	M2 x 2

II.4. Mounting: ANS scanners

The large range ANS piezo scanners are made from titanium. The main body has one, two, or three connectors (depending on type) that need to be connected to a scanning voltage supply.

Each scan direction of the scanner is driven by a piezoelectric ceramic stack element. These elements are typically unipolar (exception: ANSx150 which requires bipolar voltages for full scan range at cryogenic temperatures) and can only be used in the specified voltage range.

Due to the integrated flexure structures the scanner geometry is inherently fragile to shear stress.

It is strongly recommended to avoid any bending of the titanium frame/scanner housing as this may cause malfunctioning of the scanner.

As all other attocube positioners, the scanners can either be mounted on top of other attocube positioners (directly or in combination with an adapter plate where appropriate) or on a base plate.

The correct way of mounting an **ANSxy100** scanner on a base plate is described as follows:

1. The titanium frame of the scanner is mounted to a base plate with two M2 screws (see Figure 9). There should be no torque applied on any of the piezoelectric ceramic stack actuators while tightening the screws. While mounting the screws, please firmly hold the part with the threaded holes!

Figure 9: *Mounting of the ANSxy100 scanner titanium frame to a base plate.*

2. In a second step (see Figure 10) the top plate has to be carefully attached and tightened with two M2 screws. During the tightening process it is important to hold only the top plate as otherwise tightening the screws may result in uncontrolled torques onto the scanner.

Figure 10: *Mounting of the ANS scanner top plate to the titanium frame.*

The mounting instructions for all other scanners are analogous to the above mentioned one.

Please refer to the specifications sheets regarding specific screw size and maximum allowable screw length as screws that exceed this length may damage the positioner. Suitable screws for mounting the respective scanners are listed below and are part of the nanopositioning toolbox which can be purchased separately:

Model	Mounting from top		Mounting from bottom		Sample mounting	
	Qty	Screws	Qty	Screws	Qty	Screws
ANS50	2	M1.6 x 4	2	M2 x 3	2	M1.6 x 2
ANS100	2	M2 x 8	2	M2.5 x 5	2	M2 x 3
ANSxyz110	2	M2 x 8	2	M1.6 x 1	2	M2.5 x 5
ANSx150	2	M2 x 8	2	M2.5 x 5	2	M2 x 2

For mounting samples on top of any ANS scanner unit the usage of screws with appropriate length is of highest importance! Screws which are too long may execute shear forces on the piezos and titanium frames causing damages to these parts!

II.5. Sample mounting

The design of each attocube positioner and scanner offers several threads in the respective top plate which can be used to mount a sample or a specimen. Figure 11 shows the drawings of the top plate of the ANPx101. In total, there are six threads for M2x3 screws available. In case a sample holder is mounted on top of the positioner the thickness of this plate has to be taken into consideration regarding the suitable length for the screw being used.

Please refer to the specification sheets of your positioner for more information on the available threads.

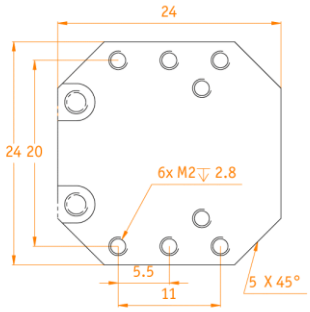


***Figure 11:** Drawing of the top plate of the ANPx101. One can attach a sample holder using the six threads M2.*

When mounting a sample holder onto a positioner it is important to follow the safety instructions given before and to make sure that no torque is applied to the positioners. It is therefore advisable to hold the top plate of the positioner during the screwing process. Figure 12 shows how a sample holder is mounted on top of a xyz-positioner stack.

Figure 12:** Mounting a sample holder on the top plate of the xyz positioner. M2 screws should be used to attach a sample plate. **The screws should not go deeper than 3 mm into the top plate!

III. Connecting positioners to the controller

attocube's Premium Line offers positioners which are either available either as open loop models or in a closed loop version with integrated encoders. Various electronic controllers together with matching software modules are provided for driving all ANP positioners enabling cutting edge experiments.

III.1. Open loop piezo controller: ANC300

The corresponding open loop controller is the ANC300 which features a completely modular design with up to seven slots for the respective driving modules as well as a touchscreen providing new ways of manual control. Generally, there are three different driving modules available:

a) ANM150 – this is the dedicated stepping module for driving ANP, ANG, and ANR coarse positioners in step mode over long travel distances.

b) ANM200 – this is the dedicated scanning module for attocubes ANS scanners. They can also be used to drive the coarse positioners in fine positioning mode.

c) ANM300 – this is the combined stepping and scanning module which offers the full functionality of both previously mentioned

Figure 13: *Open loop controller ANC300*

III.2. Closed loop piezo controller: ANC350

The ANC350 is attocube's multi-functional piezo controller which meets the demanding dynamic performance and accuracy requirements of multi-axis nanopositioning setups. The real-time operating system enables closed loop control of attocube's Premium Line positioners with integrated encoders.

The controller is available either in a 3-axes or a 6-axes version and all functionalities are accessible either via USB2.0 or Ethernet.

attocube's Premium Line positioners are either available with an integrated optoelectronic or a resistive encoder. The advantage of the optoelectronic encoder is its better position resolution and repeatability, whereas the resistive encoder can also be used in cryogenic environments.

Figure 14: *Closed loop controller ANC350*

III.3. Scan voltage amplifier: ANC250

The ANC250 is attocube's high-end scan voltage amplifier for piezo scanning tubes and flexure scanners. All three input channels (-10V...+10V) generate differential scan voltages (x+, x-, y+, y-, z) with up to 200V. The ANC250 is notable for its ultra low noise specifications with an ouput noise of only 20 µV RMS.

It is the controller of choice for driving the ANSx150 which requires bipolar voltages at cryogenic temperatures.

Figure 15: *Scan voltage amplifier ANC250*

For more detailed information on attocube's control electronics, please refer to the respective controller user manual!

III.4. Connecting positioners

Every axis of the electronic unit should be turned to "GND" before connecting the positioners!

III.4.a. Connectors & cabling on attocube positioners

If you have purchased an attocube controller with your positioner system, a set of suitable positioner control cables is delivered with the system.

attocube delivers positioners and scanners for various environments such as ambient environment (RT), High Vacuum (HV), Ultra High Vacuum (UHV), Low Temperature (LT), and combinations thereof. The positioners can either be open loop or can be equipped with position encoders, such as the Resistive (RES) or Optoelectronic encoder (NUM).

Now, the connectors on the positioners or positioners' cables, respectively, differ with environmental classification and encoder type as shown in the overview below.

		Environment					
		RT	HV	UHV	LT	LT/HV	LT/UHV
Pos Type	Open Loop	2S	2V	2V	2S	2V	2V
	RES	5R	5V	5V	5S	5V	5V
	NUM	14R	15V	15V	-	-	-

Figure 16: *Overview on positioner connectors*

Hereby, the codes for the connectors have the following meanings:

2S:	*2 pole plug standard, male*
2V:	*2 pole plug vacuum, male*
5S:	*2+3 pole plug standard, male*
5V:	*2+3 pole plug vacuum, male*
5R:	*5 pole round connector, male*
14R:	*14 pole round connector, male*
15V:	*15 pin Sub-D connector, **female***

As can also be seen from the overview, it can be said that:

- open loop positioners need two cables each,
- scanners need two cables per degree of freedom,
- RES encoded positioners require 5 cables per positioner, and
- NUM encoded positioners require 14 cables per positioner.

Note that attocubes' positioners have 30 or 50 cm cables directly attached to them, with the respective connector on them.
Only in case of open loop positioners of series ANPx/z101, ANGt/p101, and ANR101, a female connector is directly integrated into the positioner (see Figure 17). In such case, a 30 cm twisted pair copper wire (Kapton coated) with two male connectors of type 2S is delivered with the positioners.

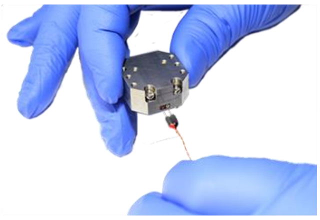


Figure 17: *Connecting the copper wires to the positioner (only necessary for RT and LT versions). Be sure to connect the cable with the correct polarity.*

For all vacuum applications, attocube delivers Kapton insulated, twisted pair copper wiring (diameter 0.2 mm) with suitable connectors (2V) directly mounted to the positioners:

Figure 18: *2-pin PEEK connector for vacuum compatible positioners*

In case of positioners with resistive sensors, an additional three wire cable (S+, S0, S-) is connected to the positioner (types 5R, 5V). Here, S+ is marked red (LT types) or marked by a bevel (vacuum types) on the respective side (see Figure 19).

Figure 19: *3-pin PEEK connector for vacuum compatible positioners with resistive encoder*

Positioners with **NUM** sensors can only be used at room temperature, either in vacuum or ambient conditions. These positioners carry a 14pin round connector (type 14R) or a 15pin vacuum compatible SubD 15pin connector (type 15V), as shown in Figure 20.

Figure 20: *Connector solutions for positioners with integrated optoelectronic encoders*
left: 14-pin Binder connector for positioners specified for ambient conditions
right: 15-pin PEEK connector for vacuum compatible positioners

III.4.b. Polarity

All attocube positioners are built with unipolar piezos. The currently only exception is the scanner ANSx150 (model which is compatible to cryogenic temperatures) which uses a bipolar piezo.

It is therefore of highest importance to connect the positioner to the controller with correct polarity to avoid depolarization or even damage of the piezo!

The 2-pin connectors on the positioners or cables are coded as shown in the table below.

The red mark on connectors used in ambient or cryogenic conditions always indicates positive polarity whereas all vacuum compatible PEEK (2- & 3-pin) connectors (see Figure 21) are chamfered on one side of the connector:

Signal Polarity	/RT, /LT	/HV, /UHV, /LT/HV, /LT/UHV
Positive	Red	Chamfered
Ground	Black	Not Chamfered

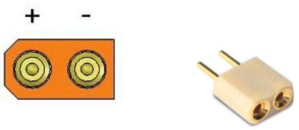


Figure 21: *The chamfered side of the 2-pin connector indicates the polarity.*

The connector pins on positioners with resistive encoders are coded as shown in the table below. The 2-pin connector is used for driving the piezo whereas the 3-pin connector refers to the resistive encoder:

Pin	/RT, /LT	/HV, /UHV, /LT/HV, /LT/UHV
Positive	Red	Chamfered
Ground	Black	Not Chamfered
V0	Red	Chamfered
SENS +	Yellow	Middle
GND	Black	Not Chamfered

The 14-pin Binder connectors and the 15-pin PEEK connectors used for positioners with integrated optoelectronic encoders can only be connected with a certain orientation which makes connecting with the right polarity an easy task.

III.4.c. Connectors on attocube's controllers

The outputs of the **ANC300** are BNC connectors, yet on the backside of the device. This open loop electronic features only signal-ground type outputs with the outer shield of the BNC connected to ground. It does not have sensor inputs; hence it can only drive attached positioners (or scanners) in open loop mode independent of the positioner type.

The **ANC350** features different output connectors, depending on the type of sensor attached to it. There are SubD Mix connectors for positioners with RES sensors, or NUM sensors and scanners available (see Figure 22).

For more details on the pin layout of these connectors, please refer to the ANC350 manual.

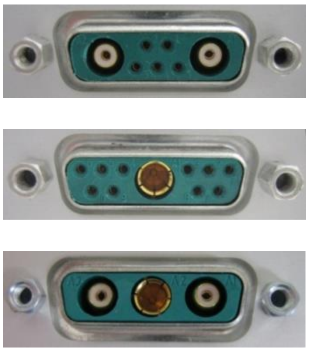


Figure 22: *SubD Mix connectors for positioners with RES sensors (top) or NUM sensors (middle), and scanners (bottom)*

III.4.d. Connection cables

All attocube positioners are delivered with a set of test cables which connect directly from the electronics to the positioners are are designed for direct table-top testing.

As a standard they feature a length of 2 m.

An overview of the available standard cables is given in the table below.

	BNC	SCN (3W3)	RES (7W2)	NUM (11W1)
2S	AAC300	AAC350/SCN		
2V	AAC300	AAC350/SCN		
5B			AAC350/RES/RT	
5S			AAC350/RES	
5V			AAC350/RES	
14B				AAC350/NUM/RT
15V				AAC350/NUM

These cables are described in the following.

The **AAC300** cable allows for connecting open loop positioners or scanners to an ANC300. It has a BNC connector on one side, while having a two pole plug on the other side. The pin layout is 1+, 1-, 2+, 2-, 3+, and 3- with 1+ marked red.

The **AAC350/SCN** allows for powering up one open loop scanner on an ANC350/SCN output. The positive contact is marked red.

The **AAC350/RES** cable allows for connecting one resistive or open loop positioner to an ANC350/RES axis:

The connection scheme on this cable is as follows:

For non-vacuum RES positioners (see Figure 23), the positive contact of the piezo drive signal is marked red and is to be connected to the red marked pin of the connection cable. The encoder cable is to be connected with the red mark towards the red mark on the female connector.

For all vacuum compatible RES positioners (see Figure 24), the positive pins are marked by bevels on the connectors. Hence, the bevels need to point to the red-marked contact on the cable connector.

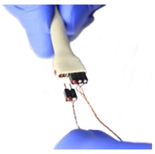


Figure 23: *Connection scheme: non-vacuum compatible RES positioners*

Figure 24: *Connection scheme: vacuum compatible RES positioners*

The **AAC350/NUM/RT** cable allows for testing NUM positioners on an ANC350/NUM axis. It features a 14pin round connector.

The **AAC350/NUM** cable with its 15pin SubD connector is suitable for all vacuum compatible NUM encoded positioners. Note that due to the connection on the positioner being female it is mandatory to use the feedthrough mockup as shown in Figure 25. This enables to use the cable also directly on a SubD-15pin feed-through.

It's important not to use a *Gender changer* as such would cross-connect the cabling. Hence, high drive voltages may be put on the encoder, thus damaging the encoder.

Figure 25: *Feedthrough mockup*

Make sure not to connect NUM cabling longer than 3m. Longer cabling may increase the sensitivity of the device to external influences.

attocube provides suitable cabling solutions with lengths up to 20 m on request!

III.4.e. Connecting positioners to the controller

Switch the ANC to GND before connecting the positioner control cable to the ANC.

Now connect the male and female connectors to the test cable making sure to observe the correct polarity. In case you are mounting the xyz-positioner in a dedicated sample holder, please use extra care in checking the polarity of your wiring before connecting the xyz-positioner to the ANC controller.

Refer to the respective controller manual for correct usage of the controller itself.

For a first testing of the coarse positioner setup it is recommended to set the amplitude to a value of 30 V and the frequency to 1000 Hz. When applying stepping voltage pulses to the positioner, one should hear a high frequency buzz and see the top plate moving in one direction. By switching up- and downwards (either the toggle switch in manual control or the respective button in the software) one can change the direction of the motion.

Always switch the electronics to GND mode during cooling down or warming up of the system.

During temperature changes, the piezo will change its length and therefore, charges may accumulate. To avoid static charges that might damage the positioner, it is recommended connecting the cabling to the ANC and switch it to GND mode or off.

III.4.f. Electrical feedthrough solutions

Currently, attocube offers several kinds of electrical feedthrough solutions depending on environmental conditions and positioners. Of course, all feedthroughs can be modified to fit the customer's needs.

In order to better describe the variety of vacuum feedthroughs, attocube uses the following naming scheme, explained here for e.g. the *VFT3/RES/CF40* feedthrough solution (see also the following page for examples)*:*

VFT: short for "Vacuum Feed-Through"

3: describes the number of cables on the outside and of connectors inside,

/RES: describes the type of output on the electronics and type of positioner connector inside the chamber,

/CF40: is the type and size of flange used (this determines also the type of connectors and cabling inside).

For selecting the right choice for the application, the main criterion is certainly the type of output (as described before) as well as the number of positioners to be wired.

The following flange types are available: KF40, and KF63 flanges for HV and LT (o-ring sealed), as well as CF40 and CF63 flanges (see Figure 26 and Figure 27) for UHV applications (copper gasket sealed). Depending on the size, they allow for different feedthroughs.

KF40 allows for the implementation of one SubD feed-through, a KF63 flange can be equipped with three SubD feedthroughs.

Standard cabling lengths are 2 m outside the chamber and 0.5 m inside the chamber (woven Kapton flatband, see Figure 28 and Figure 29).

For a CF40 or KF40 flange with a SubD-15pin feedthrough, the diameter of the attaching inner tube needs to be 38 mm or more in order to fit the connector.

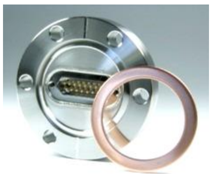


Figure 26: *CF40 flange with one SubD-15pin feedthrough*

Figure 27: *CF63 flange with three SubD-15pin feedthroughs*

Figure 28: *UHV compatible cabling for positioners with NUM encoder*

Figure 29: *UHV compatible cabling for positioners with RES encoder*

IV. Resonance frequency measurements

To gain insight to these parameters, attocube has measured the resonance frequencies and stiffnesses for most standard positioners. These measurements have mainly been conducted using interferometric measurement techniques, i.e. the attoFPSensor.

Figure 30: *Interferometric setup for measurements of resonance frequencies*

In a typical measurement (see Figure 30) a single positioner or a stack of positioners is excited using a vibration source and the response of the positioner is measured.

Typically, the internal piezo of a positioner is used as a vibration source by applying a sine voltage of varying frequency or a chirp signal. The response of the positioner to the said excitation is usually measured as amplitude and as phase signal (Figure 31). In this figure, the resonance frequency can be identified as the position where the phase signal shifts by 180°. For the given data, the resonance is located at approximately 2.5kHz. The quality factor of the resonance can be estimated as

$$Q = \frac{f_0}{FWHM}$$

where *FWHM* is the "full width at half maximum" of the resonance and f_0 the resonance frequency of the unloaded system. In this example, *Q* calculates to approximately 2515Hz/75Hz=33.

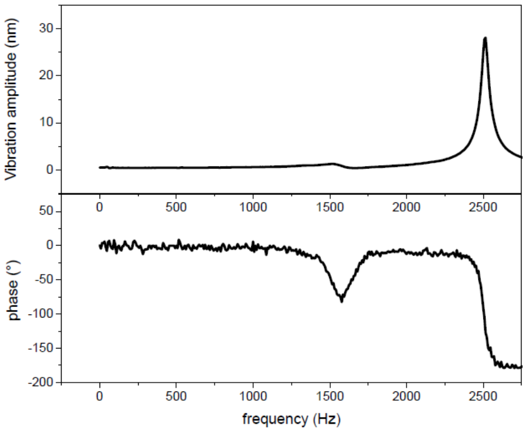


Figure 31: *Resonance spectrum of an ANPz101*

In a second set of measurements, the positioner to be tested is loaded with a known test mass M_1 and the new resonance frequency is determined, yielding f_1. From the shift in resonance frequency *(f0-f1)*, the stiffness *K* of the system is calculated. The math behind this measurement is given by two simple equations which are:

$$\omega_0 = \sqrt{\frac{K}{m_0}} \quad ; \quad \omega_1 = \sqrt{\frac{K}{m_0 + M_1}}$$

where *m0* is the intrinsic mass resting on the piezo (which is difficult to measure by other techniques). Note that the cyclic frequency ω equals 2πf. From those two equations and the measured resonance frequencies *f0* and *f1,* the stiffness calculates as

$$K\left[\frac{N}{m}\right] = \frac{\omega_1^2 M_1}{\left(1-\frac{\omega_1^2}{\omega_0^2}\right)} = \frac{4\pi^2 f_1^2 M_1}{\left(1-\frac{f_1^2}{f_0^2}\right)}$$

The native unit of *K* according to the above formula is [kg/s²] which equals [N/m]. To simplify life, we typically specify *K* in terms of [N/µm], since this makes up simpler numbers. Values are typically between 0.05N/µm for scanners and close to 1N/µm for (z) positioners.

If the stiffness *K* and the resonance frequency f_0 are known, one can calculate the resonance frequency under any applied load. To do so, one simply needs to use the formula

$$f_{res}(m) = \frac{1}{2\pi}\sqrt{\frac{K}{m_0 + m}}$$

where *m* is an arbitrary mass mounted onto the positioner (unit kg). The intrinsic mass m_0 can be calculated using

$$m_0 = \frac{K}{4\pi^2 f_0^2}$$

where *f0* is the first resonance of the unloaded setup as described previously. Typical values for *m0* are of order 0.001-0.003 kg (i.e. a few grams). The table below provides information on some values measured for x and z positioners of the 51 and 101 families:

POS	f0 [Hz]	f1 [Hz]	M1 [kg]	K [N/µm]	m0 [g]
ANPx51	2460.9	609.4	0.025	0.39	1.63
ANPz51	2585.9	976.6	0.025	1.09	4.16
ANPx101	1039.1	515.6	0.025	0.35	8.1
ANPz101	1332	390.6	0.105	0.69	9.8

Note that in a typical SPM setup, the ANPz101 positioner is loaded with approximately 50g of weight (positioners and scanners), decreasing its resonance frequency to 400-500Hz. This is in good correspondence to what can be observed in the spectral noise measurements of AFM/STM under certain circumstances.

V. Preventive Maintenance

attocube's Premium Line positioners are manufactured from high quality materials by well trained personnel. For ensuring proper functionality during the complete life time of any positioner, preventive maintenance on a regular basis is recommended.

The life time of a standard Premium Line positioner is in the order of 50,000 travel cycles at ambient conditions. The total life time may be affected depending on customizations regarding clamping forces allowing for higher loads, environmental conditions in the experimenter's setup, actual mounting, and use within the specific application.

Preventive maintenance is recommended on a regular basis and may include testing of the actual performance of the positioner.
Due to the friction based working principle the lubrication of the axis degrades over time but can be renewed at attocube at any time.
All available encoders are calibrated at attocube during the production process. A re-calibration may be taken into consideration for the maintenance.
For positioners with integrated ceramic bearings for optimized performance regarding load and runout, preventive maintenance after 10,000 travel cycles is advisable.

For further information, please contact attocube's support department:

support@attocube.com

VI. Questions & Answers: Troubleshooting

Q) What happens if the polarity is inverted, i.e. if I connect the positioner the other way around? How can I check and prevent this?

A) If the polarities are reversed, the direction of movement is inverted. This can be a way of checking whether a positioner is connected with the right polarity. Try to move the positioner with maximum 15% of the maximum voltage. If the positioner moves “inward”(x-positiners)/”down” (z-positioners), winhen the direction “outward”(x-positioners)/”up” (z-positioners) is wanted, then it is probably connected in the wrong way.
Note that this voltage could be smaller than the starting voltage, depending on the type of positioner, and the positioner won’t move at all. In this case the only method to find the right polarity is to check the cable connections.

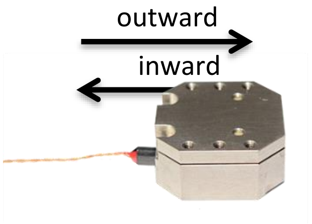


Figure 32: *Definition “inward”/”outward” movement for x-positioners*

Warning: At voltages higher than 15% of the maximum voltage applied with the wrong polarity, the piezo will be de-polarized and may be re-polarized in the other direction! Hence, the direction of movement may be reversed and the positioner will act as when connected normal. However, re-polarizing the positioner can often damage the piezo. Some piezos may not be reversely polarized at all, as they might loose capacitance.

A repolarization can be achieved by following a certain repolarization procedure:

a) It has to be made sure that the piezos are connected with the right polarity to a DC voltage.
b) Apply 10 V DC over 1 minute
c) Apply 20V DC over 1 minute
d) Increase the DC voltage in increments of 10 V and apply it for 1 minute each
e) Stop the procedure as soon as the maximum specified applicable voltage has been applied over 1 minute

Q) The positioner is not moving properly.

A) This might have several reasons. Please check that the following issues are fulfilled and are not the cause of the problem:
- Is the capacitance as expected? If not, the piezo might be broken or disconnected.
- Is the positioner mounted to a base? It is important that the positioner is rigidly mounted so that the inertial impulse can be generated properly.
- Is the positioner free to move? If it is blocked by external objects, it might not be able to move.
- Have you tried to vary the frequency and the voltage? Sometimes the positioner may stick a little. For limited times, you may also apply the maximum tunable voltage & frequency.
- Can you measure infinite resistance between “+” & “-“ of the connector? Otherwise, there might be a short circuit within the positioner.

- Try to isolate the error by exchanging the positioner with others and changing the cabling, the electronics (axis), etc. Is the problem within the positioner? Can you hear the buzzing sound?
- Is your cabling low-Ohmic (less than 5 Ohm)? If not, the positioners step efficiency will go down or stop the positioner completely. Please measure all cabling from the electronics to the connector of the positioner.
- Are there any cold solder points in your setup? If yes, they might cause a loose contact, especially when going to cryogenic temperatures.

Q) Can the positioner operate in high magnetic fields?

A) Yes, the positioners have been extensively used at high magnetic fields up to 31 Tesla. The positioner unit is made exclusively from Titanium (non-magnetic) and other non-magnetic components. Positioners with integrated optoelectronic encoders are specified for magnetic fields of up to 7 Tesla.

Q) I want to use the xyz positioner for AFM or other SPM. Can I use it for the fine motion control (with continuous voltage changes), as well as for the coarse motion control (with steps)?

A) The xyz-positioners are not primarily intended to act as scanners. At ambient conditions for example, the piezoelectric actuators in the ANPx101 allow for a scan range of 5 µm and 800 nm at 4 K.

Another possible configuration is to use a dedicated piezo scanner, e.g. the ANSxy100 mounted on top of the xyz-positioners in order to scan large scale images. In this configuration, the positioners are only used for coarse positioning.

Q) What are the differences of the performance at ambient condions and at cryogenic temperatures?

A) The main difference is due to the significantly reduced piezoelectric coefficients at cryogenic temperatures. This means that at ambient conditions motion is initiated with stepping pulses of about 5 – 30 V (depending on type and model), whereas at 4 K stepping pulses typically higher than 40 V are needed to initiate the motion (again depending on type and model).

Q) What are the performance characteristics at ultra low temperatures using He3 or a dilution cryostat?

A) The positioners have been successfully tested in dilution cryostats down to the temperature of 10 mK. The heat load of the positioners was still acceptable. When driving at full speed, the bath heated up to about 100 – 150 mK only. This heating is mostly due to friction and most systems moving at those temperatures would heat the bath in this way. To measure, one could stop the positioners and wait until the measurement temperature is reached again. To reduce the heat load one can always reduce the frequency of the steps as well as the step size.
The actuators built into the positioners are piezoelectric ceramics, which at such low temperatures behave almost like perfect capacitors, so the heat generated from the actuators is not expected to exceed the sub microwatt range.

Q) I want to reduce the heat load on the cryostat. Can I connect the positioners using resistive wires?

A) Resistive wires are not recommended. A resistance of 10 Ohms may be enough to prevent the positioners from working, as they require high currents (at low temperature about 0.5 to 1 A maximum). Alternatively, one can use superconducting wires reducing the heat transfer without increasing the resistance, or resistive wires with big diameters, respectively. Also, we suggest applying a combination of different techniques.

attocube systems
Eglfinger Weg 2
D - 85540 Haar, Germany
Phone: +49 89 420 797-0
Fax: +49 89 420 797-201 90
E-Mail: info@attocube.com
www.attocube.com

For technical queries, contact:
support@attocube.com

North America Support Hotlines:

+1 212 962 6930 (East Coast Office)
+1 510 649 9245 (West Coast Office)

South America Support Hotline:

+1 510 649 9245