Zurich actuator characteristics

Author	*Laboratory*
A. Gadola	**UZH**

Approved by	*Laboratory*

List of Abbreviations			

History		
Edition	Date	Observation
0.1	08.05.2018	Initialise document
1.0	20.09.2018	Update of some information and rephrasing after the AMC meeting in Zurich in Sept. 2018, file renamed
1.01	16.10.2018	Added play for fix point according to spherical joint measurements
1.02	21.11.2018	Changed some wording in the specification table
1.03	30.11.2018	Change doc title and file name from specifications to characteristics, change some wording in the specification table, changed specs table 2

Distribution	SST, MST, LST, Mirrors

- Table of Contents -

THE ZURICH ACTUATOR

1.1 Introduction

The CTA telescopes use tessellated mirrors to collect and focus the incoming light onto the camera's active plane. These mirrors need to be aligned to achieve an optimal optical imaging. While the smaller and middle telescopes have a more rigid metal structure and hence will not deform and bend much while elevate the telescope, the large telescope with its less rigid carbon fiber tube structure and its huge dimensions will do so. Hence, an alignment of the mirrors is not only needed after first mirror installation or on a regular monthly/annual base but rather on every change of elevation angle. The alignment can either be done by using a passive system with personnel adjusting each mirror in the telescope structure by hand or automatically with an active mirror control system using remotely controlled actuators as the hereby presented Zurich actuator system. This actuator system can be used in a continuous way but is also suited for a once in a year alignment strategy since it features position-locking even in the powerless state.

The Zurich actuator is a development, initially based on the MAGIC actuator design, which can serve the needs of all CTA telescope sizes. The key-features are a wireless communication, self-locking mechanics to maintain the position even without power, built-in memory for look-up position tables, reliable precise positioning and IP68 weather seal. The actuator system is divided into sets, each operating a mirror with a fix point and two active actuators with one and two degree of freedom suspension.

1.2 Functionality

A simple way to describe the working principal of the actuator system is to think of a painting on a wall. The nail is fixed at the top middle to balance the painting. This corresponds to the fix point of the actuator set. The weight is held by the fix point. The two active parts, the actuators, push and pull the lower edges of the painting (mirror) in order to tilt/align it to the desired position. Mounted correctly, no rotation of the mirror is introduced. An actuator thus is a high-precision linear motor.

This document will only describe the actuator set in its technical characteristics while the aligning process of the mirrors is described elsewhere. As mentioned above, the actuators push and pull the mirrors at two edges to bring them into the right position. The actuator internally uses a stepper motor and a mechanics to translate the rotational into a linear movement. The stepper motor is driven by the electronics to a given angular position or by a number of full or part turns. The desired position or the number of turns is sent to the actuator over a wireless communication using the IEEE industry standard 802.15.4. Simple commands can be sent to have the actuator perform some action or to have it returning information like serial number, current position or internal temperature and humidity. All commands are listed in the appendix in Table 6.

1.2.1 Communication

The actuator features wireless communication via XBee modules [xbee] that allow an implement of communication protocols like ZigBee or IEEE 802.15.4 standard. Later is used to reduce the large overhead of the ZigBee protocol. XBee allows a network topology with coordinators having a predefined PAN ID (Personal Area Network identification) and end-devices connecting only to the assigned coordinator via the PAN ID. This topology prevents interferences with actuators of e.g. nearby telescopes or other hardware using XBee modules or the 802.15.4 protocol. Several coordinators might be installed for full signal coverage of all actuators in a telescope. More details about XBee 802.15.4 can be found in R. Gredig's bachelor thesis [roman]. The final implementation topology of the network is up to the end user.

Each actuator features a nonvolatile memory with lookup tables with programmable predefined positions. A single broadcasted command will move all actuators to the stored position according to e.g. the given elevation angle.

1.2.2 Mechanics

The actuator features a custom made stepper motor coupled to a high precision spindle with 1 mm thread pitch. A nut running on the spindle translates rotational into linear movement and positions the stamp of the actuator into the selected position (Figure 1). The stamp runs inside a sliding film and a ball head is attached at the end to allow the mirror movement without introducing shear strain. The flange finally interfaces with the mirror through four M4 screws. The flange's diameter should be form locking with the mirror flange to prevent strain on the screws in case of an earthquake. The sealing of the actuator's inner parts happens at three positions; the power connector is rated IP68 (only with correctly screwed and sealed counterpart plug or dust cover), the bellow seals around the ball head and allows length change of the actuator, the flange seals with an O-ring towards the mirror flange.
The absolute positioning system is split into two subsystems both using Hall sensors. One system [4] detects the position of the stepper motor and resolves one full turn into 256 steps corresponding to an angular resolution of 1.4° or a position resolution of the stamp of 3.9 µm. The second system [12] detects the position along the moving stamp resolving millimeters. Combining both the information allows an absolute positioning of the actuator below 5 µm.

Figure 1 shows a sectional drawing of the actuator with the most important parts labeled and described below.

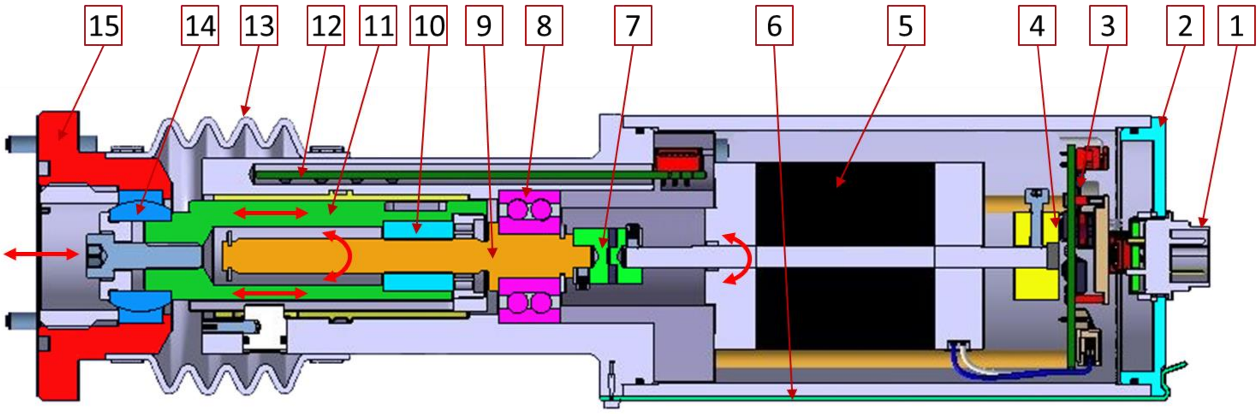


Figure 1: Sectional drawing of the actuator with all important parts visible.

Table 1: Mechanics and electronics parts of the actuator as shown in Figure 1.

1. Power connector 24VDC, IP68 (with connected plug)	9. Spindle
2. Plastic cover (can be remove to access electronics)	10. Nut connected to stamp
3. Electronics boards with wireless module	11. Stamp
4. Angle transmitter for absolute positioning	12. Hall sensors for absolute positioning
5. Stepper motor	13. Bellow for sealing
6. Spring clip	14. Ball joint
7. Clutch	15. Flange
8. Ball bearing	

The electronics is powered by 24 VDC and features the XBee module as well as a PIC and stepper motor driver.

1.3 Characteristics

1.3.1 Electrical and mechanical characteristics

Table 2 lists the electrical and mechanical characteristics of the actuator set version D.

Electrical characteristics:		**Note:**
Absolute maximum supply voltage	26 VDC	
Operating voltage range	18 – 24 VDC	
Operating current	≤ 850 mA @ 24 VDC	
Standby current	≤ 50 mA @ 24 VDC	
Communication	Wireless, industry standard (IEEE 802.15.4)	
Connectors	1 connector for power supply	Lumberg 0314 03
Built-in memory	4096 bytes = 2048 elevation angles	Lookup table
Mechanical characteristics:		
Dimensions of single actuator Exclusive gimbal parts	(261 – 297) mm x 65 mm (L x Ø)	Measured from power connector to flange with fully retracted/extended actuator.
Dimensions of fix point	184 mm x 65 mm	
Weight Fix point	1716 g (1-dof actuator + gimbal) 1911 g (2-dof actuator + two gimbal) 615 g (incl. nuts and washers)	
Positioning	Absolute	Hall sensors
Positioning precision	±5 µm	
Mechanical clearance (fix point)	±1 µm	Spherical joint only
Mechanical clearance (1dof)	±(15 + 10) µm (actuator + gimbal)	
Mechanical clearance (2dof)	±(15 + 20) µm (actuator + two gimbal)	
Elevation speed	1.2 mm/s (1 ms delay), minimal torque 0.8 mm/s (2 ms delay) 0.6 mm/s (3 ms delay) 0.5 mm/s (4 ms delay), maximal torque	Delay command see appendix.
Maximal stroke length	36 mm	For calibration only.
Operational stroke length	34 mm	
Maximal force needed to tilt flange	5 Nm	Due to friction of spherical ball joint
Maximum tilting angle of flange (spherical joint)	15°	
Maximum moving force	700 N	
Longitudinal survival force	9’500 N	
Holding force	Self-locking	
Degree of protection	IP 68	Only applicable with mounted power plug or dust cap and attached to mirror flange with O-ring.
Storage and shipment temperature	10°C ÷ 50°C	
Operation temperature	-5°C ÷ 25°C	

Survival temperature	-15°C ÷ 50°C	With/without power

Table 2: Characteristics of the Zurich actuator set version D.

Lightning protection level is not defined. Two tests with an actuator and an XBee unit have been performed during 2016 by Jose Miguel Miranda (G. Pruteanu was also present) at LCOE (Laboratorio Central Oficial de Electrotecnia) in Madrid, Spain. Figure 3 shows the test setup at the lab and Figure 2 shows the initiated pulse shape. Two tests have been performed:

- Lightning strike next (no direct hit) to actuator with no cable attached and an XBee unit with an electromagnetic pulse of 100 kA with 25 µs rise time and three echoes.
- Lightning strike next to actuator with attached cable (open ends, no loops) and an XBee unit with an electromagnetic pulse of 120 kA and same pulse shape.

Both units survived the tests without any damage.

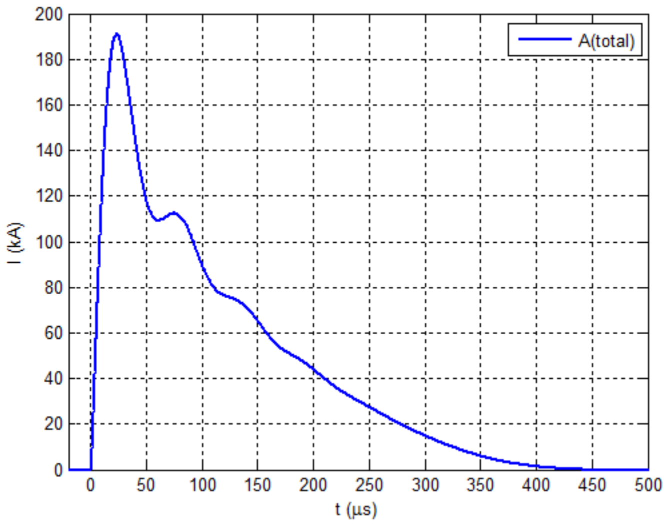


Figure 2: Induced lightning pulse shape (by courtesy of J. Miranda and LCOE). Shape was inspired by aircraft industry standard EUROCAE-ED-84 / ARP5412.

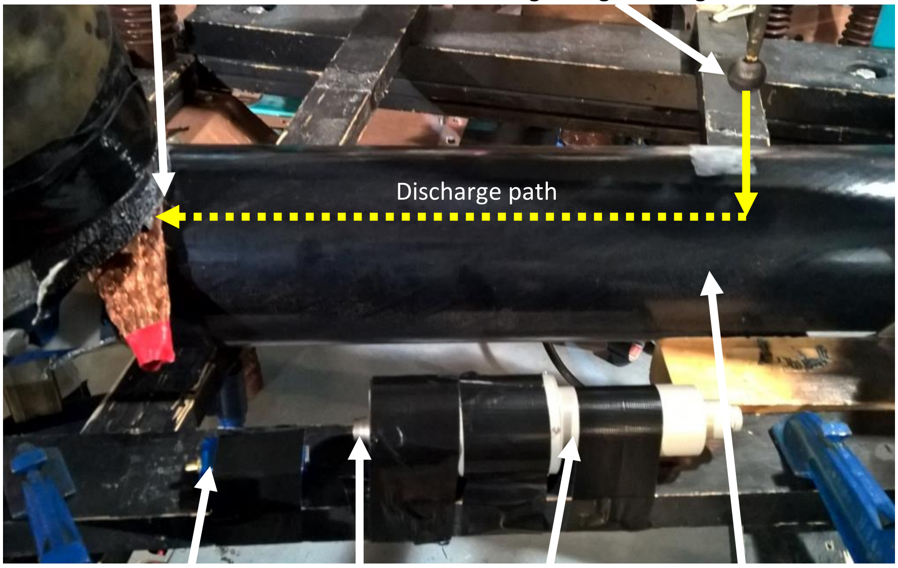


Figure 3: Lightning test with actuator and XBee unit. The carbon fiber tube is struck by the lightning. The actuator and XBee unit are mounted at a distance of 10 cm to the tube (by courtesy of J. Miranda).

1.3.2 Software characteristics

The electronics is based on a PIC18F25K40. The source code and a procedure to use the bootloader for reprogramming the PIC via XBee will be made available as soon as a final version exists.

Table 6 in the appendix lists all commands and their formats for controlling the actuators. A serial console like PuTTY can be used to control the actuator.

1.4 Deliverables

The actuator set comes in a carton box with the rough dimensions (230 x 240 x 270) mm (WxLxH). Figure 4 shows and Table 3 lists the content of a box.

Table 3: Deliverables of an actuator set.

Amount	Position
1	Fix point
1	1 dof actuator
1	2 dof actuator
4	Axes
12	M4 hexagon socket screws
3	O-ring (36 mm inner diameter and 3 mm thickness)
2	M22 nuts
2	washers with 23 mm diameter

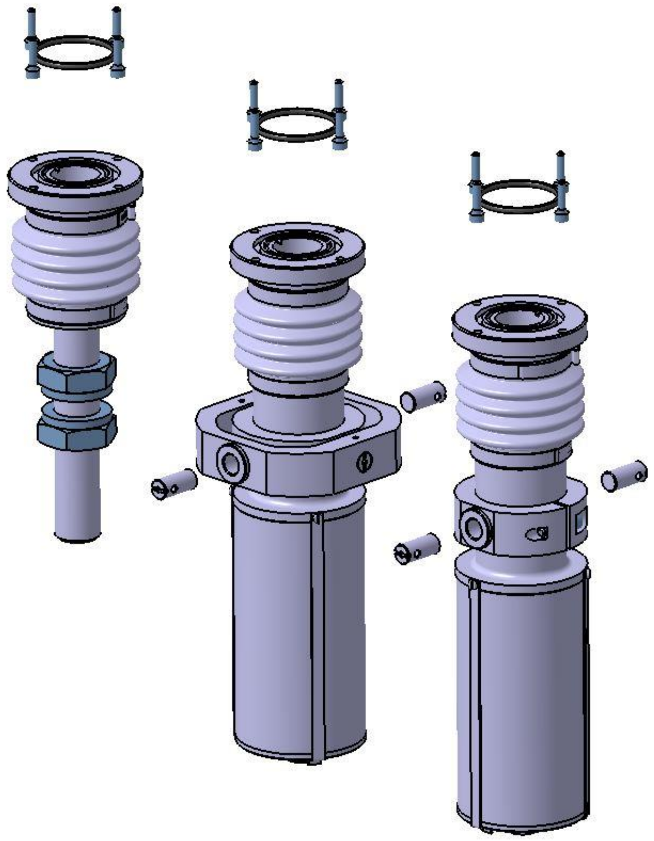


Figure 4: Actuator set with all deliverables as mentioned in the text.

1.5 Interfaces

1.5.1 Electrical interface

The actuator is powered via a three pin connector (Figure 5) from Lumberg (part number 0314 03 (actuator side) and 0322 03 (plug)). Note that the Lumberg connector and hence the actuator is only watertight when mounted properly with an intact O-ring inside the plug (replacement O-ring for the connector should have inner diameter of 17 mm and a thickness of 1 mm) and a watertight mount of the cable. The delivered power to each actuator should not be less than 24 W.

Figure 5: Three pin connector on actuator side. Pin assignment: pin 1 =GND, pin 2 = NC, pin 3 = +24VDC.

1.5.2 Mechanical interface

There are two mechanical interfaces, the flange to the mirror and the gimbal axes to the mounting triangle of the dish.

1.5.2.1 Interface to mirror

The actuator's flange diameter has been changed slightly from version C to D to allow form locking with the mirror flange. This should prevent shear strain on the M4 screws connecting the actuator with the mirror flange during e.g. an earth quake. Hence, it is recommended to install mirrors with the new form locking flange to make use of this functionality. Appendix sections 2.3.1 and 2.3.2 show the dimensions of a proposed form locking mirror flange and of the actuator flange. Also shown in the mirror flange drawing 2.3.1 as shaded area is the area where the O-ring seals the actuator. This surface must have a roughness of at least N8 to assure proper sealing.

1.5.2.2 Interface to dish

The mechanical interface to the dish/triangle is given with the two axes of the gimbals of the 1dof and 2dof as well as the M22 thread of the fix point, which comes with two M22 nuts. The technical drawings can be found in 2.3.3 and 2.3.4. The axes (Figure 6) may be held in place with roll pins or splints. A dedicated hole with a diameter of 3 mm is foreseen.

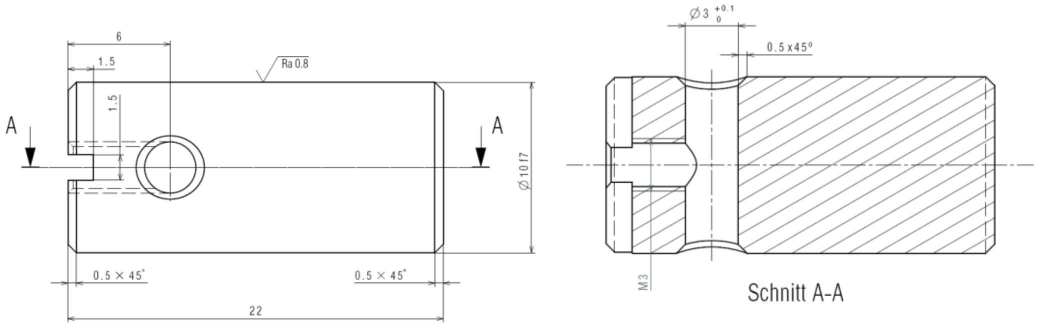


Figure 6: Stainless steel (1.4404) axis with 3mm hole for pin and side-slit for positioning.

1.5.3 Communication interface

The communication is realized with the wireless standard IEEE 802.15.4 at 2.4 GHz.

1.6 Installation notes

The installed actuator system is shown in Figure 7. The fix point must be mounted directly above or below the mirror's center of gravity to allow it to carry the load of the mirror. It is recommended to orient the 1-dof gimbal axis perpendicular or near perpendicular to the direction between the 1-dof actuator and the fix point.

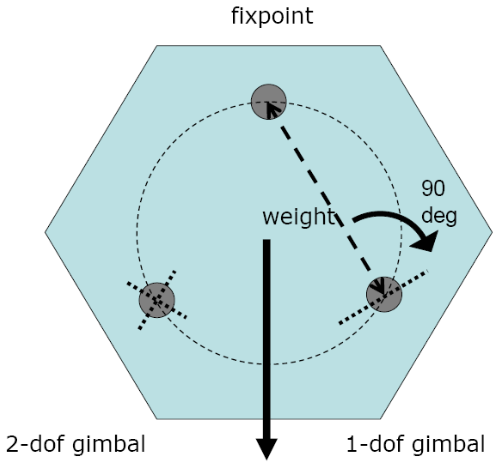


Figure 7: Position of the fix point and proposed orientation of the 1-dof actuator axis referenced to the fix point.

1.7 Steering of the actuators / control commandos

The actuators can be steered individually or in the so called broadcasting mode where all actuators are addressed at the same time. In normal operation only the dish's elevation angle is sent to all actuators and the actuators read the individual positions from their look-up tables. To keep the communication fast no feedback from the individual actuators is sent, although this feature is implemented and tested and ready to be activated if needed.

1.7.1 Notes and recommendations on working with the actuator

The delay command (*Dxx*, see appendix) defines the speed of the motor and hence influences its torque. It is recommended to set the delay to 4 ms (send command *D04*) for a precise movement of the actuator since the stepper motor might lose a step under load with a low delay setting (e.g. 1 ms). The maximum torque is achieved with a delay of 4 ms.

1.8 Serial numbering

The actuators are all labeled with a unique human and machine readable serial number. A simple QR code reader is sufficient to extract all information from the QR code. Information can e.g. be fed directly into a database (e.g. together with the mirror and its position in the telescope's structure). Figure 8 shows an example of the label. The serial number is coded such that it contains the version of the actuator mechanics, a unique continuous integer number, the date of production and the producing institution. The format used is:

v-nnnnnn-yy/mm-ppp

v: first character denotes the version (e.g. D).
nnnnnn: six digit continuous and unique serial number
yy/mm: year / month of production (e.g. 18/04)
ppp: name of producing institution

The QR code is generated with 25x25 elements with a level H error correction (reconstruction of up to 30%

of damaged data).

Figure 8: Example of a QR code as can be found on an actuator with all necessary information about the actuator. The stored information is D-012345-18/04-UZH.

1.9 Versioning (history)

The first actuator prototype has been presented to the CTA members in 2008 at the general meeting in Padova. Many improvements have since been implemented and the design has reached maturity. Table 4 shows the different versions of the actuators.

Table 4: Production versions of the Zurich actuator.

Version	Description	Changes
A	Production during 2011. Installed on MST prototype.	Initial version.
B	Production during 2012. Installed on MST prototype.	Very small changes and small series produced.
C	Production during 2013/2014. Installed on the LST1 at La Palma in 2018.	Changed fork design from one part to a three part design for more efficient production. Introduction of the spring clips for better and faster assembling. Stronger motor for 700N.
D	Production during 2018/2019.	Changed several mechanical parts to better fit the different tolerances so mass production is more reliable. Introduced boot-loader and a new DC-DC converter circuit with better performance (higher MTBF). Flange is now form-locking. Fork is no longer part of the set. Humidity sensor installed.

1.10 Maintenance

The actuator system is maintenance-free. Defective devices should be replaced and disposed accordingly. Repair of a device is not foreseen.

Attached connectors and the bellow should undergo a regular (e.g. yearly) visual inspection to check proper sealing.

The electronics and the inner parts of the actuator can be accessed by unclipping the three spring clips and gently pulling the end cap e.g. with the power connector. Only qualified and instructed personnel should perform repair work on the actuator since failing of reassembling the device correctly can lead to mechanical damage, water ingress and malfunction.

1.11 Spare policy

The following Table 5 gives an estimated number of actuator sets needed for the different telescope types.

There will be more spares for the active parts (actuators) than for the fix point. The number of spare sets will be about 10% of the total number produced (see Table 5). Storing space needed for the spares can be calculated with the following numbers; 60 sets can be stored on a euro-pallet with a 1200 mm high frame.

Table 5: Number of actuator sets and spares.

Type	**Threshold/Baseline**	**Number of sets**	**Total sets**	**Spares**	**Operation** (adoption with present knowledge)
SST	50 / 70	19	950 / 1330	1%	Used for mirror installation, replacement only
MST	20 / 40	86	1720 / 3440	10%	Used for mirror installation, replacement and once a month for realignment
LST	4 / 8	206	824 / 1648	20%	Used for mirror installation, replacement and constantly during operation
			3494 / 6418	350 / 690	

2. APPENDIX

2.1 Command set

Table 6 lists all commands available for firmware version 2.03.

2.1.1 General comments

The following notes should be considered:

- All commands are case sensitive.
- All commands need to be fully sent correctly within 2 seconds, starting from entry of the first character. Exceeding the time will result in a reset of the internal state machine (no movement of the actuator involved).
- An actuator reset does not change the position of the actuator but only resets the internal state machines.
- No carriage return (CR) should be sent at the end of a command.
- Switching DEBUG-mode on/off influences the amount of data being returned by an actuator.
- All number entries are hexadecimal (0..9,A..F).
- All return messages terminate with 0x0D 0x0A (CR LF).
- If the actuator is driven into a jammed position it will automatically send a 'JAMMED' message.

2.1.2 Format of position frame

The format of the position frame is given as

aabb ccdd eeff gghh ii jj kk (CR LF)

Value	Description
aabb, ccdd, eeff, gghh	16-bit hexadecimal values of ADC sensors [1..4], used for debug purpose only
ii	mm value of position (hexadecimal)
jj	sub-mm value of position (multiples of 1/256th mm, hexadecimal)
kk	index of dominant hall sensor for position determination [1..4] (internally not used anymore, kept for legacy purposes)

Example: Sending the command *p* returns the position frame *01D6 0099 0306 0241 12 10 03*, which corresponds to *h12 = d18* and *h10 = d16* (ignore everything but *ii* and *jj*). The absolute position is hence 18.06(25) mm.

2.1.3 Commands

Table 6: Command syntax for the actuator.

Command Syntax	Description	Return value (DEBUG mode ON/OFF)
l	drive one step inwards (5 µm)	position frame / none
L	drive one turn inwards (1 mm)	position frame / none
r	drive one step outwards (5 µm)	position frame / none
R	drive one turn outwards (1 mm)	position frame / none
<	Drive inwards until jammed or	After each step:

	character received	position frame / none
>	Drive outwards until jammed or character received	After each step: position frame / none
Pxxyy	Programmed drive: goto position xxyy with xx being in units of ‘mm’ and yy in units of 1/256th of 1 mm. All values are hexadecimal. (*)	position frame / none
#	Re-calibrate actuator: drive all inwards until mechanical limit, rewrite internal lookup table (LUT)	Calibration progress
V	Print version number	‘AMC Control, C Firmware 2.03 08/2012’
Dxx	Set delay between individual stepper motor steps in units of ms. Influences the speed, available torque and positioning precision when driving with the L/R command (not with Pxxyy).	‘Delay: xx ms’
d	Read back delay	‘Delay: xx ms’
Mxxyyzz	Write elevation lookup table: xx: elevation angle (integer) yy: actuator position (mm value) zz: actuator position (1/256th of 1 mm)	‘Verify: xx yy zz’
mxx	Read back elevation lookup table: xx: elevation angle (integer)	‘Verify: xx yy zz’ (yy zz being of same format as for writing the elevation table)
T	Read internal temperatur of actuator	‘+029.2’ (example)
H	Read internal temperature and humidity of actuator (+tt.t/hh)	‘+29.2/42’ (example)
Gxx	Goto position associated with elevation angle xx from elevation lookup table	position frame / none
!	Toggle DEBUG mode	‘DEBUG ON’/’DEBUG OFF’
p	Print current position	Position frame
$	Binary memory dump of elevation lookup table	180 characters, 2 characters each for elevation entries 0...89 deg

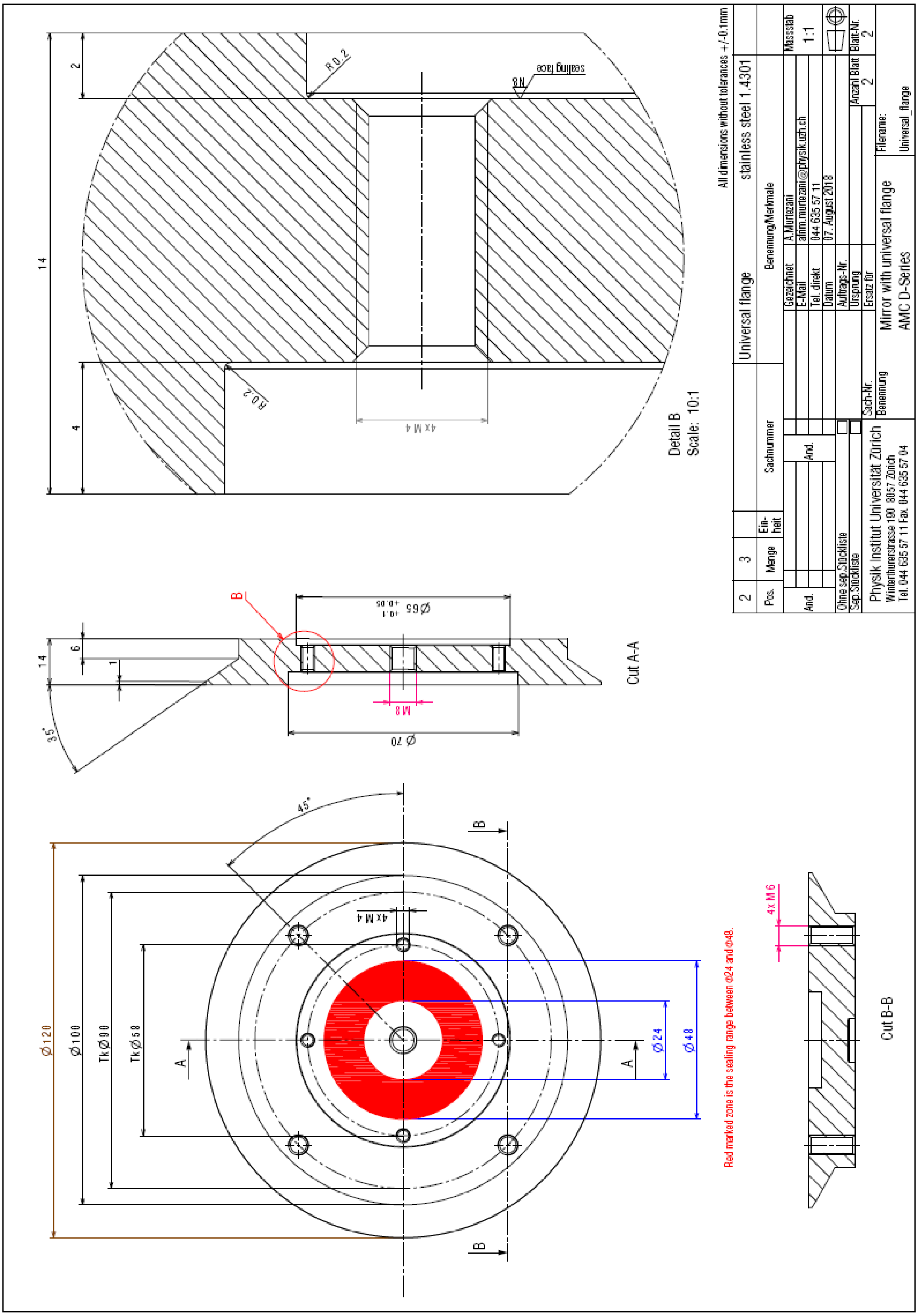
(*) The full stroke of the actuator is 36 mm. 1 mm at each end of this range is used for calibration purposes only. The useable range is hence 34 mm. It is not possible with the P-command to drive the actuator outside of the 34 mm region. The first six commands (driving manually with L,l,R,r,<,>) allow to drive outside of the 34 mm and into the actuator’s limits and should only be used by experts and with care.

2.2 References

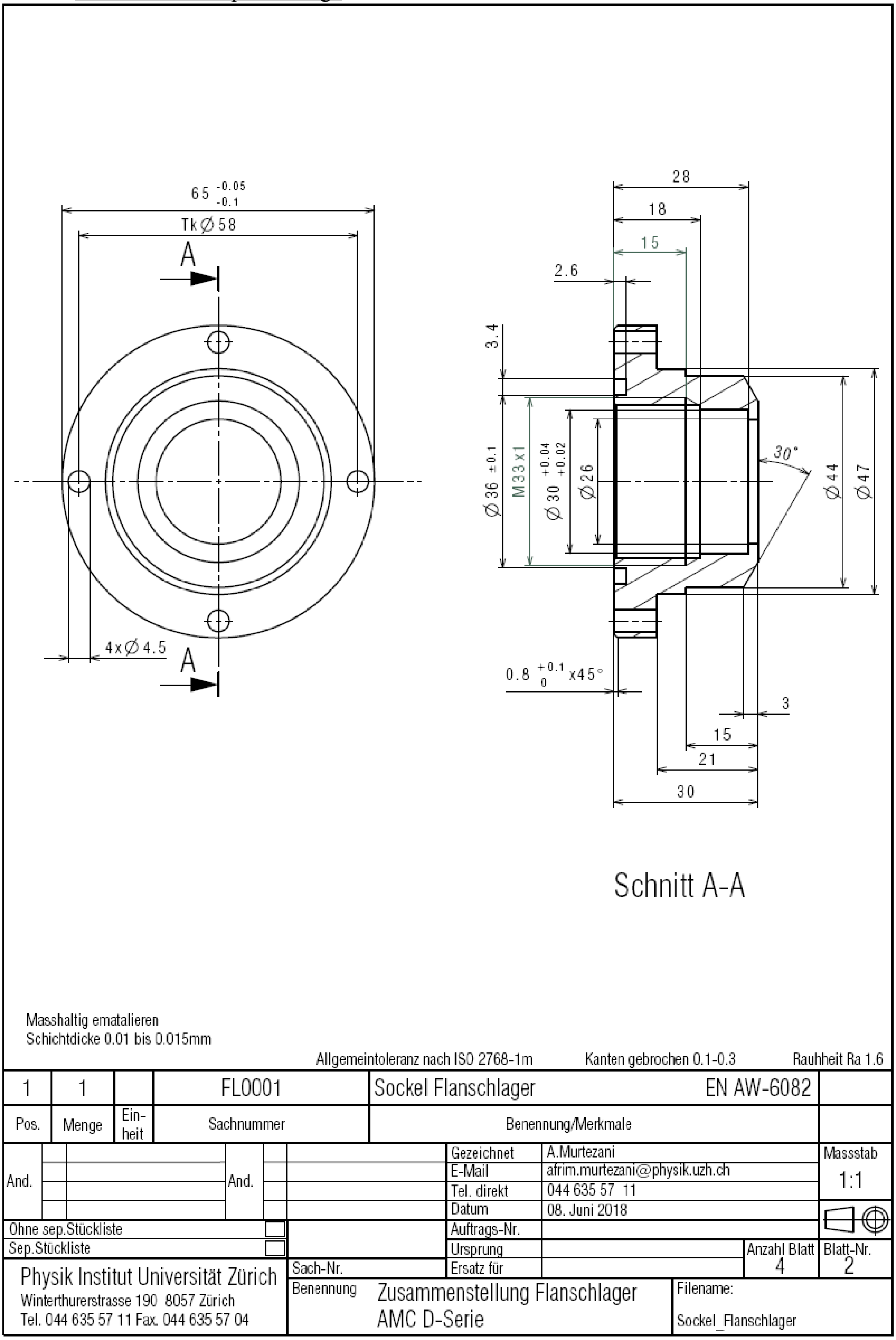
[xbee] https://www.digi.com/xbee
[roman] Roman Gredig Bachelor Thesis 2009, http://cta.physik.uzh.ch/public/theses/

2.3 Drawings

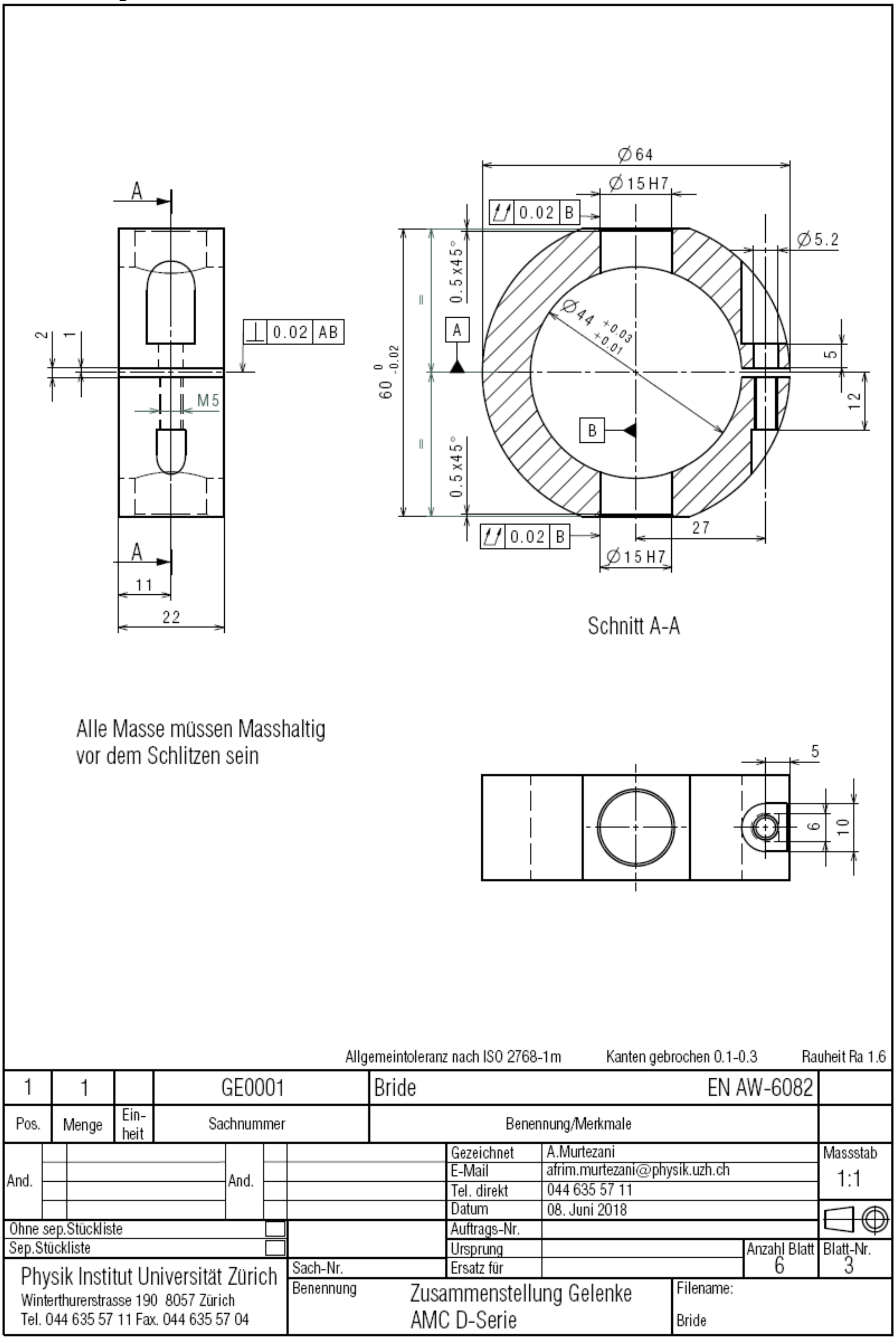
2.3.1 Proposed mirror flange for form locking



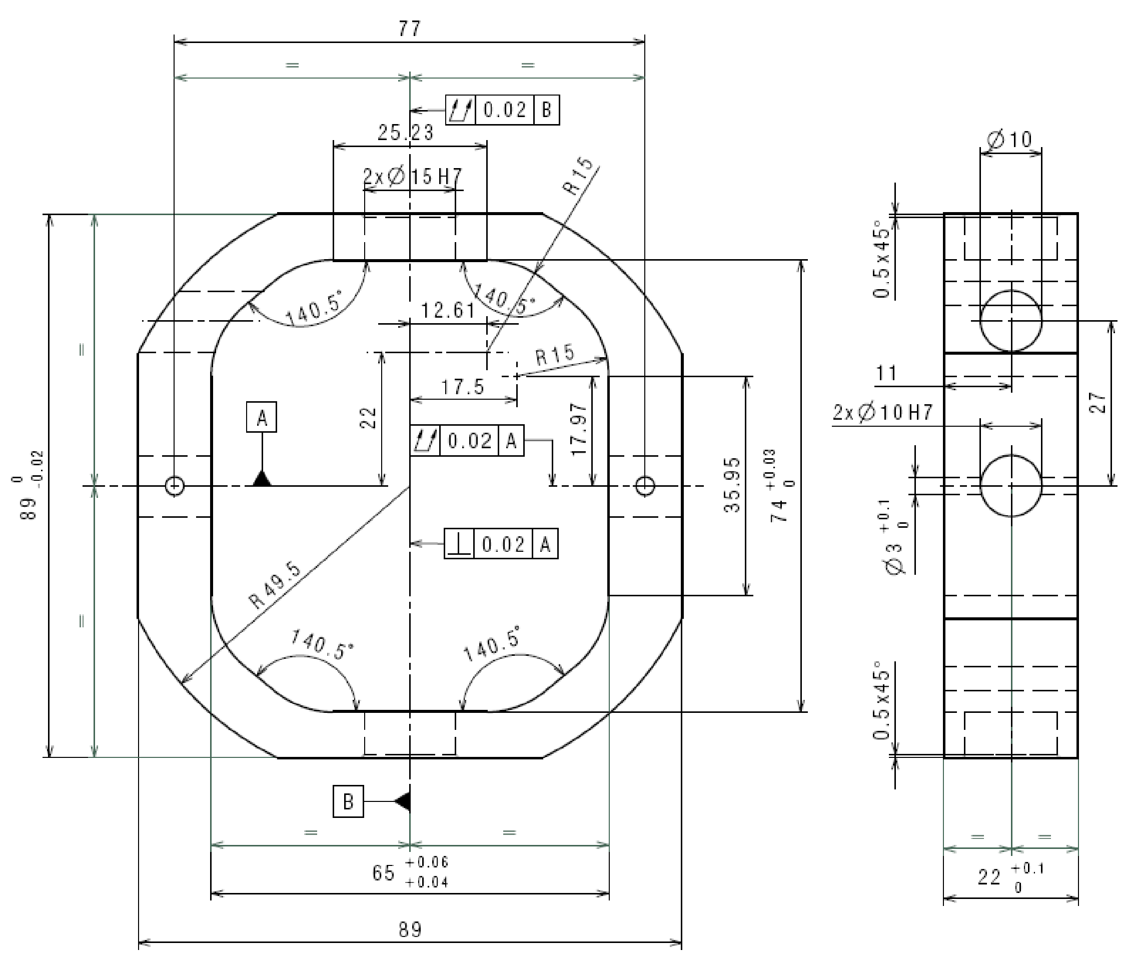
2.3.2 Actuator and fix point flange



2.3.3 1dof gimbal



2.3.4 2 dof gimbal



Allgemeintoleranz nach ISO 2768-1m Kanten gebrochen 0.1-0.3 Rauheit Ra 1.6

3	1		GE0003	Innengelenk EN AW-6082	
Pos.	Menge	Ein-heit	Sachnummer	Benennung/Merkmale	

And.	And.	Gezeichnet	A.Murtezani
		E-Mail	afrim.murtezani@physik.uzh.ch
		Tel. direkt	044 635 57 11
		Datum	24. Juli 2018
Ohne sep.Stückliste		Auftrags-Nr.	
Sep.Stückliste		Ursprung	
	Sach-Nr.	Ersatz für	

Massstab 1:1

Anzahl Blatt 5 | Blatt-Nr. 3

Physik Institut Universität Zürich
Winterthurerstrasse 190 8057 Zürich
Tel. 044 635 57 11 Fax. 044 635 57 04

Benennung: Zusammenstellung Gelenke AMC D-Serie

Filename: Innengelenk