Project N°: IST-1999-13109
Acronym: REHAROB

TECHNICAL DOCUMENTATION OF THE NON-COMMERCIAL PART OF THE 3D MOTION THERAPY MONITORING SYSTEM

Part 1:
Design and development of an artificial (dummy) limb

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RÈSUMÈ

Deliverable 9 summarizes the biomechanical and mathematical date used for the design and the development of a dummy upper human limb, as a part of the REHAROB's Physiotherapy Monitoring and Documentation System.

Contents

1. Description of the problem and requirements

Development of an artificial (dummy) upper limb with built in force/torque sensors for the test of the dynamic behavior of the REHAROB station.

During the development of the Dummy limb the following requirements were defined:

- Adaptive lengths of the two upper limb segments – the Dummy limb has to cover a wide range of possible patients with diverse physical characteristics and thus different lengths of the upper and lower arms;
- Simulate variable resistance in the arm joints
- Cover the motion range of the human arm – the dummy limb is to be able to perform all movements of a human upper limb with a typical motion range;
- Anthropomorphic format – the model has to resemble the anthropomorphic structure of a human upper limb, so that the testing of the REHAROB cell can be carried out as close as possible to the real situation with a patient;
- Simulate both left and right arms – the model has to be symmetrically neutral
- Record the motion trajectory of the model and F/T data
- Execute all rehabilitation exercises
- Include the shoulder-clavical complex

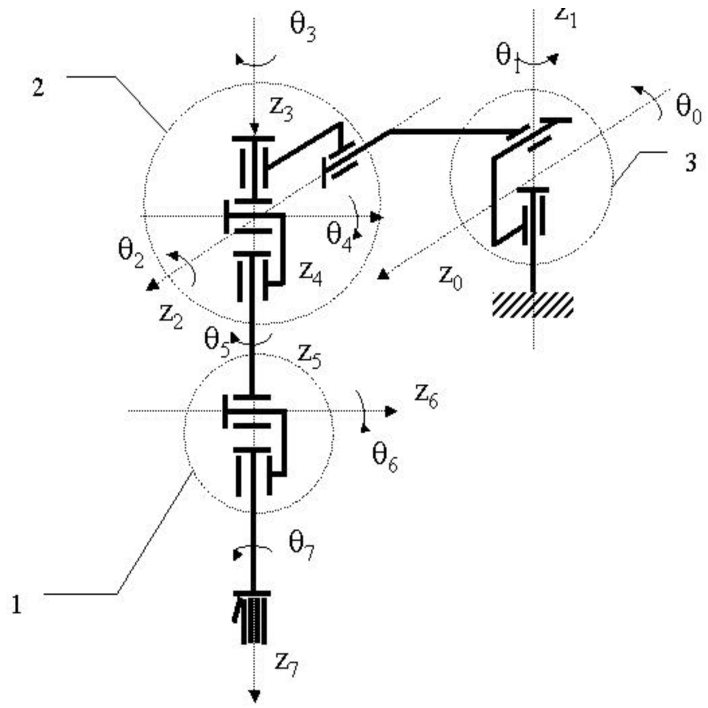
2. Calculations concerning the construction, reasoned results of design

The upper limb as an object of mechanic-mathematical modeling is considered as a system of rigid bodies (links), connected by specific method. The simplifications in the creation of the model consist not only the number of the links (bones), but also their shape, the type of the kinematics couples (joints) and the forces acting at the model links (muscle forces).
The bones are modeled as rigid links, which geometry must be taken into account for determination of the co-ordinates of the muscle tendons' capture places and the mass centers, while the joints are modeled as an ideal kinematics couples. The defined in that way kinematics schemes allowed the use of different mechanic methods, theory of the mechanisms and machines for the investigation of the modeled object.
The modeling of the bones as rigid links could be assumed as a good enough approximation, because the processes in the soft tissues, the blood movement and the muscle's deformation do not influence the mass-inertia characteristics of the links.

Never the less that the experiments shows that the center of rotation of the joints during a real movement is placed not in a point but in a small area, the error in calculation of the shoulders of the muscle forces is between 2.5%- 3.1% if we assume that the center of rotation is a point. The coefficient of friction in the joints is very small - from 0.003 to 0.025 and the energy losses for surmounting the friction are small too. In that case the joints could be assumed with good approximation for ideal kinematics couples. This is true if we take in account only the constrains in the joints movements provoked of the friction between the joints surfaces. But restrictions among the movement have also the joint capsule and the ligaments. They restrict the movement to an anatomically acceptable. This anatomically acceptable swish depends certainly also from the shape of the joints surfaces.

The kinematical structure of the model (Fig.1) must imitate the movements in clavicle attached to the sternum joint (retraction – protraction and elevation – depression), in the shoulder joint (abduction – adduction, flexion – extension and internal – external rotation) and in the elbow joint (flexion – extension and pronation – supination).

To make possible the estimation of the F/T parameters during the various joint movements and in order to realize controlled resistance reactions the kinematics structure of the model is developed as an open kinematics chain. It is built from R couples of V^{th} class. The clavicle attached to the sternum joint is organized by two couples which axes cross point corresponds to the location of the physical center of this joint. Two couples also realize the elbow joint. More different is the shoulder joint. In the model is imitated a spherical joint by four R couples of V^{th} class, defining fixed center of rotation corresponding to the physical center of the joint. The input of redundancy in the kinematics schema of the shoulder joint is determined by the necessity of overcoming possible singularity arising in joints organized with three R couples of V^{th} class.



To a bigger part it is dependant to the requirement the dummy limb to be as close as possible to the shape and parameters of the human arm. There is a potentiomentric sensor built in each kinematics couple for measurement of the current joint coordinate. The imitation of muscle resistance (spasm) is executed by DC motor-gearboxes and servo brakes. The change of the forces and torques of the fore and upper arm joints is measured by 6 component F/T sensors.

2.1 Geometrical and force parameters of the model

The model's realization and the choice of its components depend on the solutions of the tasks, formulated below:

- *Geometrical parameters of the links;*
- *Imitation of the resistant reactions;*
- *Imitation of the threshold's values restrictions of the joints' angles during the separate movements;*
- *Fixation of the initial position of the model before starting the teaching process and before its grasping by the robots;*
- *What is the maximum resistant torques at the ligaments?*

Table 1 – Geometrical parameters of the model

Segment	*Anthropomorphic length, cm*	*Segment's length, cm*	*Weight, kg*
Upper arm	35.9	32	2.8
Fore arm	26.6	28.5	1.4
Hand	20.4	7.4	0.35

Some tentatively values about the resistant torques at the elbows and shoulder's joints (Fig.2) are:

Elbow's joint $T_{elbow} \tilde{}$ 18 N x 0.18 m = 3.2 N.m
Shoulder's joint $T_{shoulder} \tilde{}$ 28 N x 0.16 m + 18 N x 0.5 m = 13.5 N.m

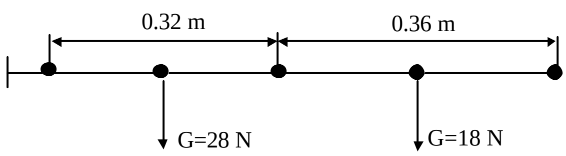


Fig.2

The torque about the shoulder's joint has a significant meaning. An electromagnet brake creating such a resistant torque has a weight around 1.3 kg and dimensions 85 mm X 47 mm. The weight of the three brakes, which would be specified about the three movements at the shoulder's joint, would vastly exceed the weight of the forearm (segment). The weight of the electromagnet brakes at the elbows joint is about 1.5 kg and dimensions 60 mm X 43 mm.

Where to position the F/T sensors?
The F/T sensors have to be fitted near the joints. If they were positioned after the joints, would have to load not only the force loads, but also the load from the weight of the joints and the resistant elements in them. More expediently is that the F/T sensors to be fitted before the joints. The F/T sensors will be more sensitive to the external force acting over the model at this case.

What should be the measurement ranges of the F/T sensors?

Table 2 - Geometrical and general parameters:

Part	Mass Kg	Length M	Position of centers of mass in L.C.S., m			Principal torques of inertia, Kg.m^2		
			x	y	z	I_{xx}	I_{yy}	I_{zz}
Upper arm	2.1	0.305	0.146	0	0	2,285. 10^{-3}	17,88. 10^{-3}	17,88. 10^{-3}
Lower arm	1.275	0.270	0.110	0	0	0,25. 10^{-3}	7,06. 10^{-3}	7,06. 10^{-3}
Hand	0.45	0.190	0.076	0	0	0,38. 10^{-3}	0,38. 10^{-3}	0,38. 10^{-3}

A and B (Fig.3) are points of forces acting over the orthosis. It is considered that the relation – upper arm and forearm is divided into ratio 2:1.

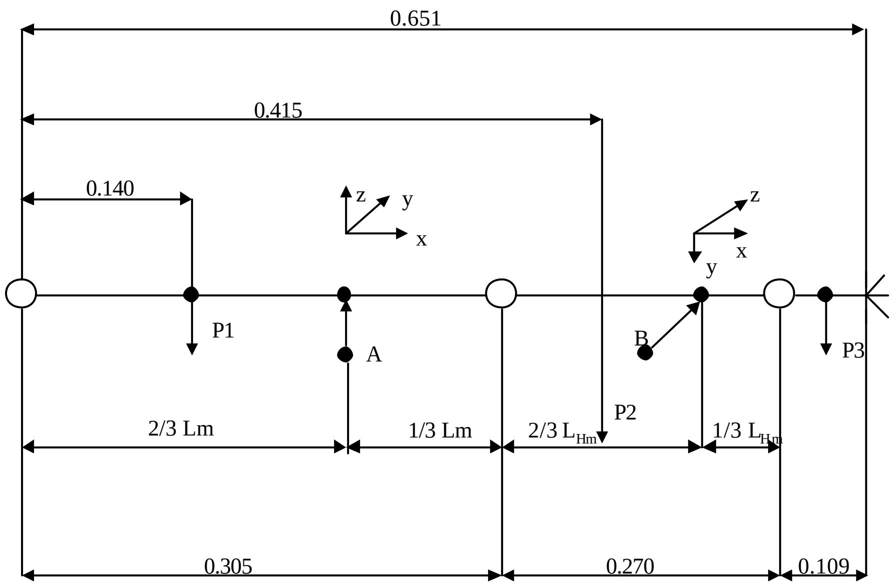


Fig.3
Forces acting over the orthosis

P_1 – weight of the upper arm = 21 N;
P_2 – weight of the forearm = 12.75 N;
P_3 – weight of the hand = 4.5 N.

Table 3 - Parameters of forces acting over the orthosis:

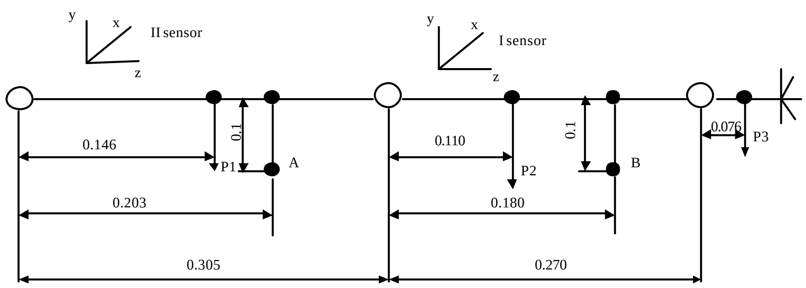
N: of the sensor	F/T N; N.m	Average value	0.5 x average value	1.5 x average value	Maximum value
1 – sensor on the forearm – 35 tests	Fx	11.73			54.7
	Fy	19.83			80
	Fz	28,13			106.2
	Tx	1,80			6.37
	Ty	1,72			7.21
	Tz	1,09			3.39
2 – sensor on the upper arm – 4 tests	Fx	120,55			240
	Fy	13,25			35
	Fz	17,55			153.9
	Tx	0,17			0.49
	Ty	2,00			6.74
	Tz	0,63			1.57
3 – compressing of the shoulder – 8 tests	Fx	0.33			0.5
	Fy	1.77			2.8
	Fz	0.73			1.05
	Tx	0.05			0.07
	Ty	0.35			0.60
	Tz	0.05			0.07

The data is collected from the results, presented by BUTE. The received maximum values, under the tests have to be considered as exceptions because significantly differ from most of the results.

2.2 Calculation of the force loads over the joints of the model

It is considered that the F/T sensors are situated near the geometrical centers of the shoulder and elbow's joints of the model (Fig.4). The moments will be calculated about co-ordinate systems with centers coinciding with the centers of the joints. The position of the orthosis changes under the different experiments in a plane, perpendicular to the axis of the corresponding unit, as the direction of the axes Y and Z. Only the direction of the axis X coincides with the axis of the unit. The signs of the F/T components are not presented and can be considered as positive.

Fig.4



The F/T sensors on the model are with a fixed position. The axis Z of the F/T sensors on the model coincides with the axis X of the sensors of the orthosis. The horizontal situation of the model is analyzed. The calculations will be about the higher of the forces Fy and Fz, because the axes Y and Z of the F/T sensors on the orthosis change their positions under the change of the positions of the orthosis towards the axes of units. It is considered that points A and B (points of force acting) are situated at distance, 0.1 m from the axes of the units. It is considered the worst case to calculate Fy and Tx, when the direction of the external force coincides with the direction of the force of the weight P. The calculations are done about two cases – there is force acting only over point B and there is force acting over both points A and B.

Force acting only over point B

Forces and torques, measured by the 1st sensor:

$F_{x1} = F_{y/zb}$;
$F_{y1} = F_{y/zb} + P_2 + P_3$;
$F_{z1} = F_{xb}$;$T_{x1} = 0.11P_2 + 0.18F_{y/zb} + 0.346P_3 + 0.1F_{xb}$; (1)
$T_{y1} = 0.180F_{y/zb}$;
$T_{z1} = 0.1F_{y/zb}$

Forces and torques, measured by the 2nd sensor:

$F_{x2} = F_{y/zb}$;
$F_{y2} = F_{y/zb} + P_1 + P2 + P_3$;
$F_{z2} = F_{xb}$;$T_{x2} = 0.146P_1 + 0.415P_2 + 0.651P_3 + 0.485F_{y/zb} + 0.1F_{xb}$; (2)
$T_{y2} = 0.485F_{y/zb}$;
$T_{z2} = 0.1F_{y/zb}$

Force acting over points A and B

Forces and torques, measured by the 1st sensor:

It could be considered that P2, P3 and the force acting can define the force load on the 1 sensor over point B. The force acting over point A has a supporting role about the elbow's joint and is not logically to consider that this force could be an assumption for movements at the elbow's joint. Because of this the components of the forces and the torques, measured by the 1 sensor can be defined using the relations (1).

Forces and torques, measured by the 2nd sensor:

$F_{x2} = F_{y/za} + F_{y/zb}$;
$F_{y2} = P_1 + P2 + P_3 +(-) F_{y/za} + F_{y/zb}$;
$F_{z2} = F_{ya} + F_{xb}$;$T_{x2} = 0.146P_1 + 0.415P_2 + 0.651P_3 +(-) 0.203F_{y/za} + 0.485F_{y/z1} + 0.1F_{xa} + F_{xb}$;
$T_{y2} = 0.203F_{y/za} + 0.485F_{y/zb}$;

$T_{Z2} = 0.1F_{y/za} + 0.1F_{y/zb}$ (3)

The resistant muscle reactions at the both joints, which would ensure the static balance of the model, are not reflected in the model for calculation the force acting. The directions of the forces $F_{y/z}$ on the points A and B under the most rehabilitation procedures is opposite. The force on point A under the motion of the elbow's joint should have supporting, not an active function. It could be considered that the high values of the forces on point A are measured during such case, where F_A compensate the action of F_B, the weight of the hand and the force reactions in the shoulder.

Results

Average values of the force components at point B:

F_{XB}=11.73 N; F_{YB}=19.83 N; F_{ZB}=28.13 N; $F_{Y/ZB}$=28.13 N (higher of the values F_{YB} and F_{ZB})

Average values of the force components at point A:

F_{XA}=120.55 N; F_{YA}=13.25 N; F_{ZA}=17.55 N; $F_{Y/ZA}$=17.55 N (higher of the values F_{YA} and F_{ZA})

Results from the dependences (1) – calculations are done regarding the average values of the force components:

F_{Y1}=48.53 N;	T_{Y1}=5.06 N.m;
F_{Z1}=11.73 N;	T_{X1}=9.20 N.m;
F_{X1}=28.13 N;	T_{Z1}=2.81 N.m

Results from the dependences (2):

F_{X2}=28.13 N;	T_{X2}=26.10 N.m;
F_{Y2}=66.38 N;	T_{Y2}=13.64 N.m;
F_{Z2}=11.73 N;	T_{Z2}=2.81 N.m

Results from the dependences (3) – plus in front of the $F_{Y/ZA}$:

F_{X2}=45.68 N;	T_{X2}=41.72 N.m;
F_{Y2}=83.93 N;	T_{Y2}=17.21 N.m;
F_{Z2}=132.28 N;	T_{Z2}=4.57 N.m

Results from the dependences (3) – minus in front of the $F_{Y/ZA}$: F_{X2}=45.68 N;

T_{X2}=34.60 N.m;

F_{Y2}=48.83 N;	T_{Y2}=17.21 N.m;
F_{Z2}=132.28 N;	T_{Z2}=4.57 N.m

Maximum values of the force components:

F_{XBmax}=54.70 N; F_{YBmax}=80 N; F_{ZBmax}=106.20 N; $F_{Y/ZBmax}$=80 N;

F_{XAmax}=240 N; F_{YAmax}=35 N; F_{ZAmax}=153.90 N; $F_{Y/ZAmax}$=240 N;

First sensor – elbow's joint

Needed ranges:

F_X=28.13 N

F_Y=48.53 N

F_Z=11.73 N

T_X=9.20 N.m

T_Y=5.06 N.m

T_Z=2.81 N.m

Second sensor – force acting only over point A

Needed ranges:

F_X=28.13 N

F_Y=66.38N

F_Z=11.73 N

T_X=26.10 N.m

T_Y=13.64 N.m

T_Z=2.81 N.m

Force acting over points A and B (minus)

Needed ranges:

F_X=45.68 N

F_Y=48.53 N

F_Z=132.28 N

T_X=34.60 N.m

T_Y=17.21 N.m

T_Z=4.57 N.m

3. Final design

The final design of the artificial human limb has 8 DOF, of which 6 are actuated by 6 DC motors and the other 2 use DC brakes, to simulate the resistance of the spasticity in the patient's arm. All DOF have an angular sensor equipped for position feedback.

Two force/torque sensors are mounted on the lower arm and upper arm segments of the dummy limb for measuring the forces and torques acting in the joints of the model.

Through telescopic bushings the lower arm and upper arm segments of the dummy limb realize the adjustable lengths of these segments. The lengths of the two segments are as follows:

Lower arm: Min = 237 mm

Max = 297 mm

Upper arm: Min = 266.5 mm
Max = 326.5 mm

The total weight of the dummy limb is around 11,4 kg. The weight of the two segments has to correspond to the average weight of the expected patients and is estimated to be as follows:

Lower arm (+ hand): Weight = 2.9 kg

Upper arm: Weight = 1.9 kg

VOLUME = 2.5940338e+06 MM^3
SURFACE AREA = 1.0704861e+06 MM^2
AVERAGE DENSITY = 4.3698260e-03 GRAM / MM^3
MASS = 1.1335476e+04 GRAM

CENTER OF GRAVITY with respect to _PM01000000 coordinate frame:
X Y Z 6.7580920e+01 -4.2295659e+01 -1.7852742e+02 MM

INERTIA with respect to _PM01000000 coordinate frame: (GRAM * MM^2)

INERTIA TENSOR:

Ixx Ixy Ixz 5.0382366e+08 8.4764829e+07 2.0836033e+08
Iyx Iyy Iyz 8.4764829e+07 8.5868011e+08 -1.1553200e+08
Izx Izy Izz 2.0836033e+08 -1.1553200e+08 4.5792933e+08

INERTIA at CENTER OF GRAVITY with respect to _PM01000000 coordinate frame: (GRAM * MM^2)

INERTIA TENSOR:

Ixx Ixy Ixz 1.2226063e+08 5.2363735e+07 7.1597272e+07
Iyx Iyy Iyz 5.2363735e+07 4.4562420e+08 -2.9938556e+07
Izx Izy Izz 7.1597272e+07 -2.9938556e+07 3.8587987e+08

PRINCIPAL MOMENTS OF INERTIA: (GRAM * MM^2)
I1 I2 I3 9.4427874e+07 3.9954996e+08 4.5978687e+08

ROTATION MATRIX from _PM01000000 orientation to PRINCIPAL AXES:

0.95401	0.28816	-0.08267
-0.16366	0.26957	-0.94897
-0.25117	0.91886	0.30433

ROTATION ANGLES from _PM01000000 orientation to PRINCIPAL AXES (degrees):
angles about x y z 72.219 -4.742 -16.807

RADII OF GYRATION with respect to PRINCIPAL AXES:
R1 R2 R3 9.1270455e+01 1.8774382e+02 2.0139950e+02 MM

MASS PROPERTIES OF COMPONENTS OF THE ASSEMBLY
(in assembly units and the _PM01000000 coordinate frame)

DENSITY MASS C.G.: X Y Z

PM01010000 MATERIAL: UNKNOWN
5.70876e-03 1.26617e+03 -3.57193e+00 9.03454e-06 -2.33156e+01

PM01030000 MATERIAL: UNKNOWN
4.32635e-03 1.28095e+03 -7.37097e+01 -4.16137e+00 -3.40000e+01

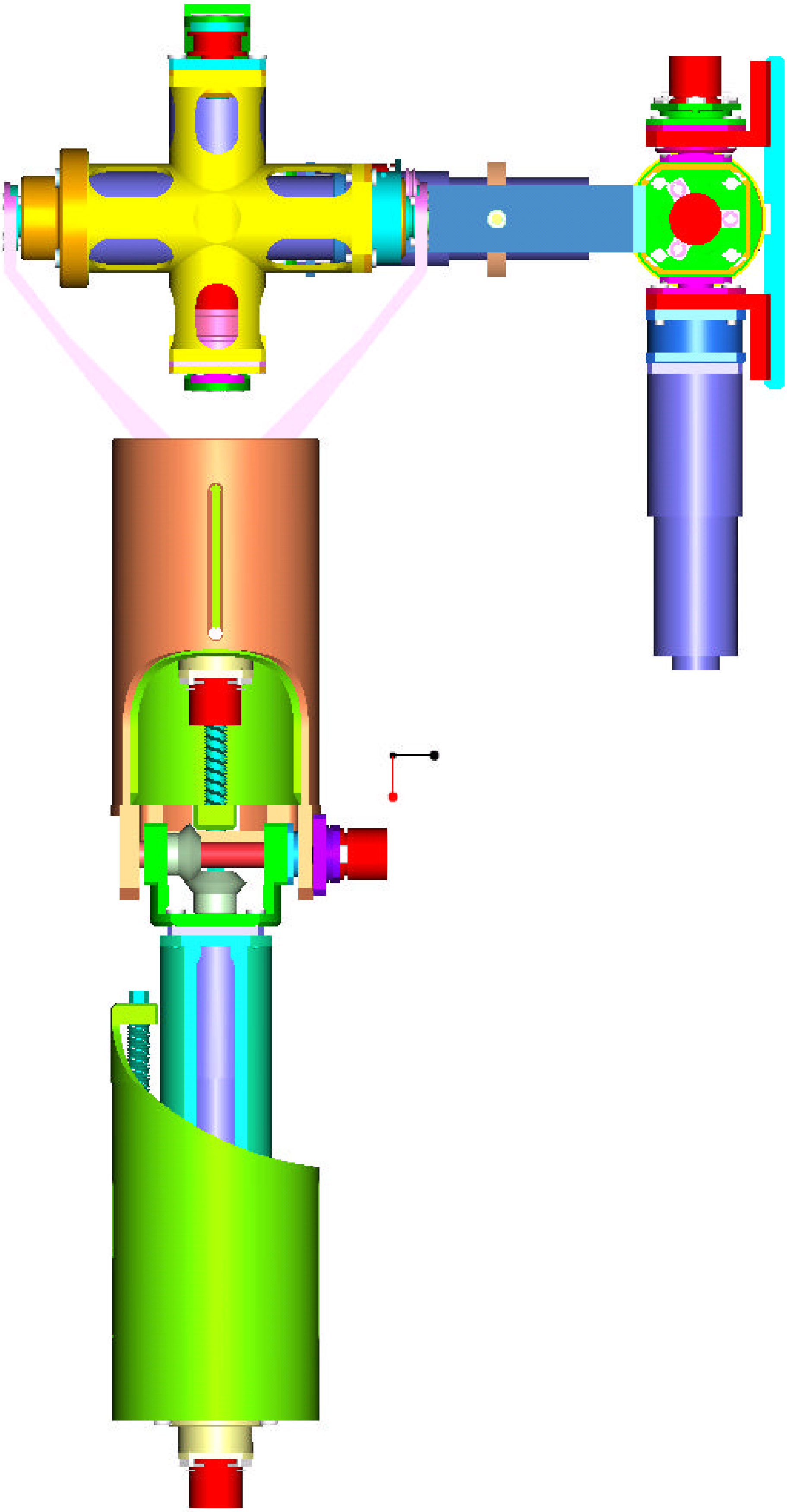
PM01020000 MATERIAL: UNKNOWN
5.47594e-03 1.40047e+03 -7.14988e+01 4.74616e+01 -1.57543e+02

PM01040000 MATERIAL: UNKNOWN
5.01962e-03 2.62021e+03 -6.97976e+01 -6.23992e+01 -2.34000e+02

PM01060000 MATERIAL: UNKNOWN
3.44446e-03 1.87823e+03 8.79845e+01 -7.72738e+01 -2.34787e+02

PM01050000 MATERIAL: UNKNOWN
3.83661e-03 2.88945e+03 3.40122e+02 -8.02721e+01 -2.33910e+02

Fig.5 Front view of the Dummy limb



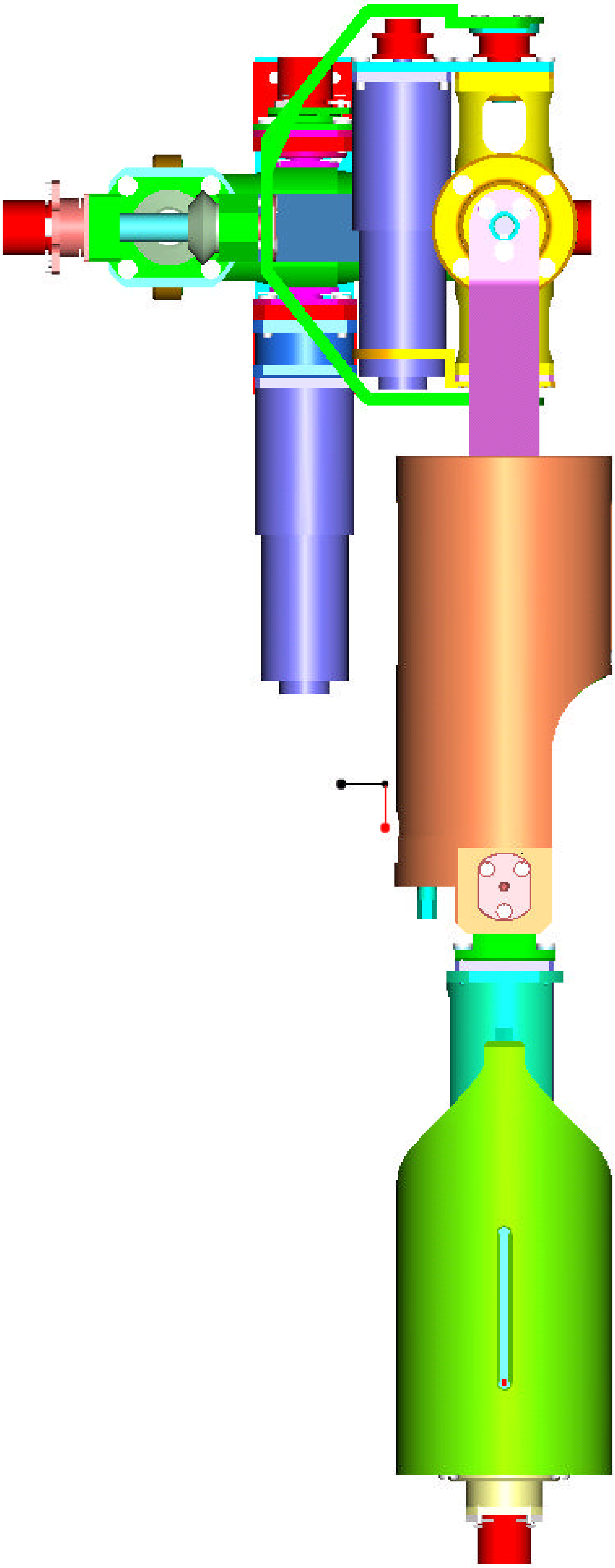


Fig.6 Side view of the Dummy limb

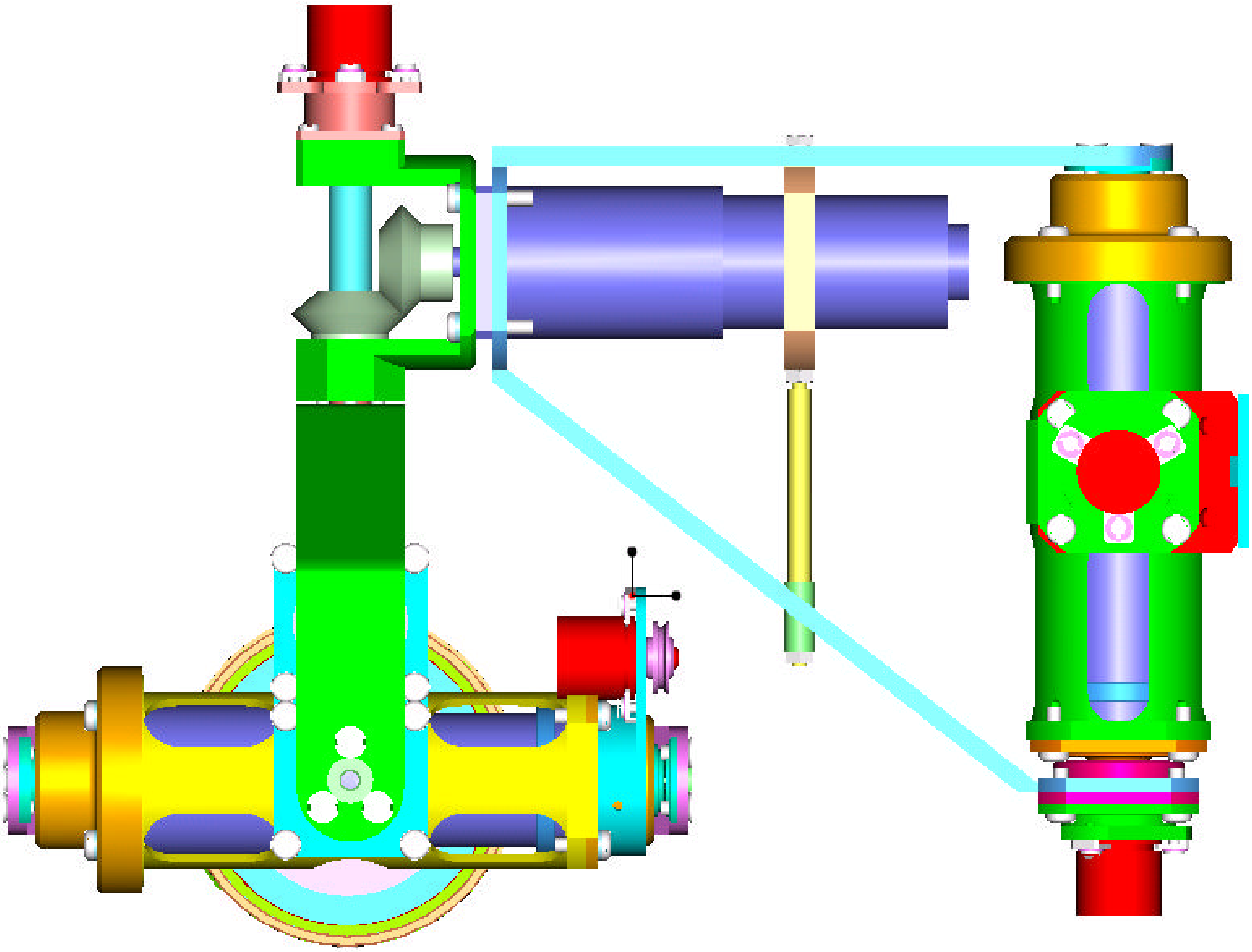


Fig7 – Top view of the Dummy limb

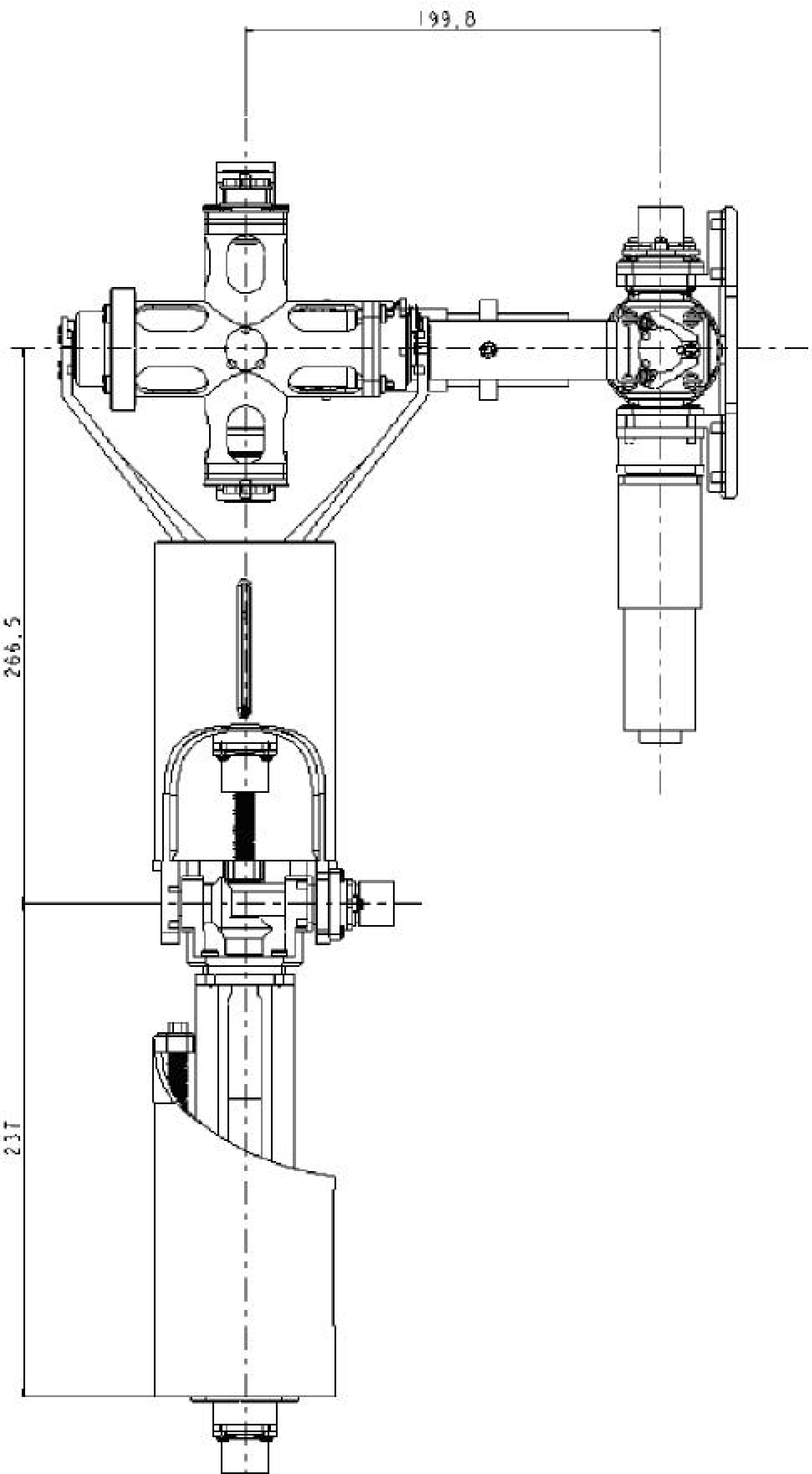


Fig.8 - Drawing (front view) of the Dummy limb

3.1 Parts list, list of components

The following table gives a list of the components of the dummy limb (PM.01.00.00.00), divided into the main assemblies.

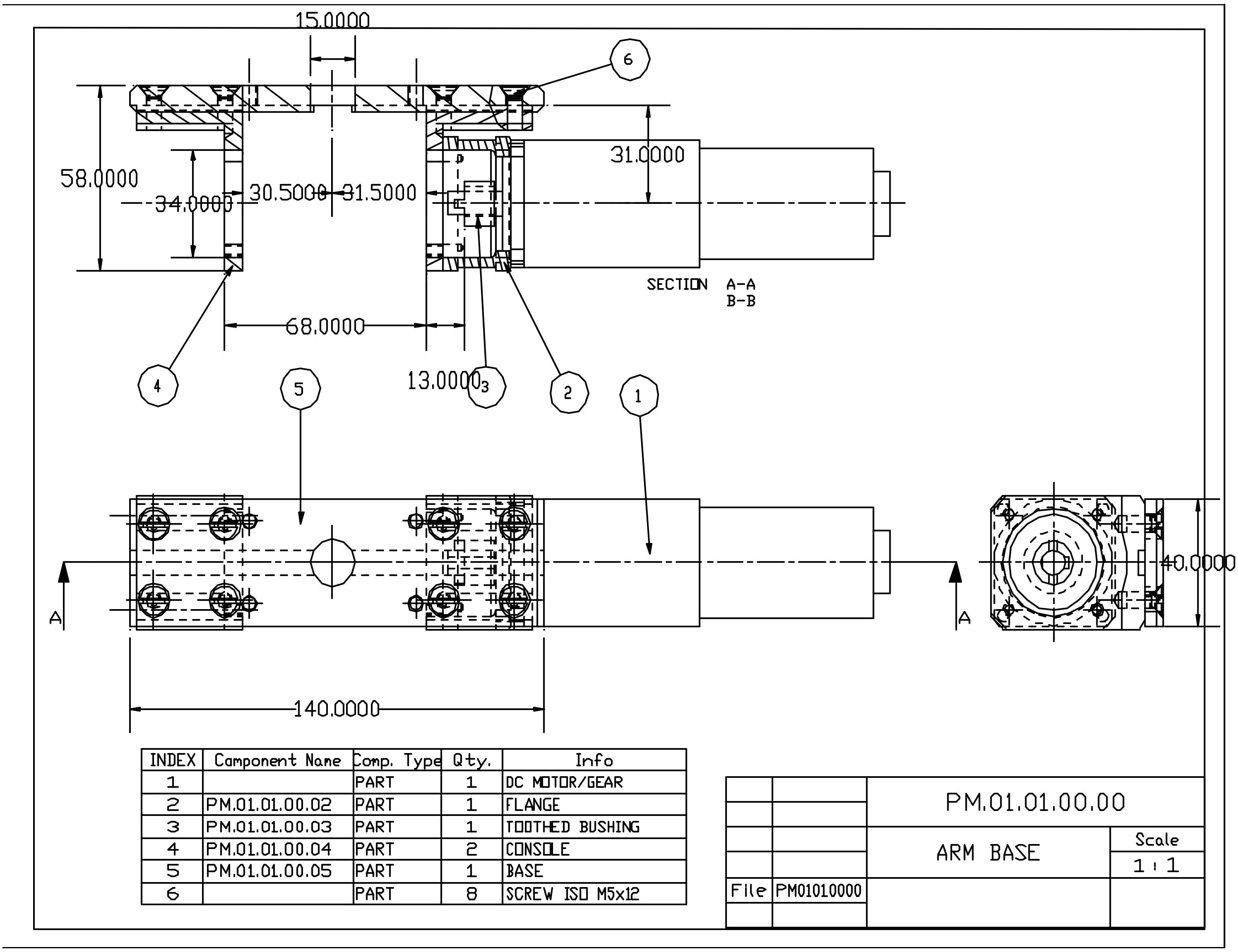
INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
1.	PM.01.01.00.00	ARM BASE	ASSEMBLY	1
1.1	PM.01.01.00.05	BASE	PART	1
1.2	PM.01.01.00.04	CONSOLE	PART	2
1.3		DC MOTOR/GEAR	PART	1
1.4	PM.01.01.00.02	FLANGE	PART	1
1.5		SCREW ISO M5X12	PART	8
1.6	PM.01.01.00.03	TOOTHED BUSHING	PART	1
2.	PM.01.02.00.00	CLAVICLE JOINT I	ASSEMBLY	1
2.1		A.S. SCREW	ASSEMBLY	4
2.2	PM.01.02.01.00	FORK	ASSEMBLY	1
2.3	PM.01.02.00.09	A.S. CONSOLE	PART	1
2.4		ANGULAR SENSOR	PART	1
2.5		BEARING 8X22X7	PART	2
2.6	PM.01.02.00.04	BEARING AXLE	PART	1
2.7	PM.01.02.00.02	CONICAL GEAR	PART	1
2.8	PM.01.02.00.05	CONICAL GEAR II	PART	1
2.9	PM.01.04.00.06	COTTER 1.8X3X15	PART	1
2.10		DC MOTOR/GEAR	PART	1
2.11	PM.01.02.00.08	NUT M8 SPECIAL	PART	1
2.12		SCREW ISO M3X8	PART	4
2.13		SCREW ISO M4X20	PART	4
2.14		SCREW ISO-M4 X 6	PART	6
2.15	PM.01.02.00.17	SHOULDER FORK	PART	1
2.16	PM.01.02.00.06	SPACER	PART	1
2.17	PM.01.02.00.10	TOOTHED BUSHING	PART	1
2.18		WASHER ISO M4	PART	4
3.	PM.01.03.00.00	CLAVICLE JOINT II	ASSEMBLY	1
3.1		A.S. SCREW	ASSEMBLY	6
3.2	PM.01.03.00.12	A.S. SUPPORT	PART	2
3.3		ANGULAR SENSOR	PART	2
3.4		BEARING N 12XN 28X 8	PART	4
3.5	PM.01.03.00.14	BEARING AXLE I	PART	1
3.6	PM.01.03.00.23	BEARING AXLE II	PART	1
3.7	PM.01.03.00.13	BEARING BED	PART	3
3.8	PM.01.04.00.08	BEARING BUSHING	PART	1
3.9	PM.01.04.00.05	BUSH	PART	1
3.10	PM.01.03.00.17	CAP	PART	1
3.11		CIRCLIP D28	PART	1

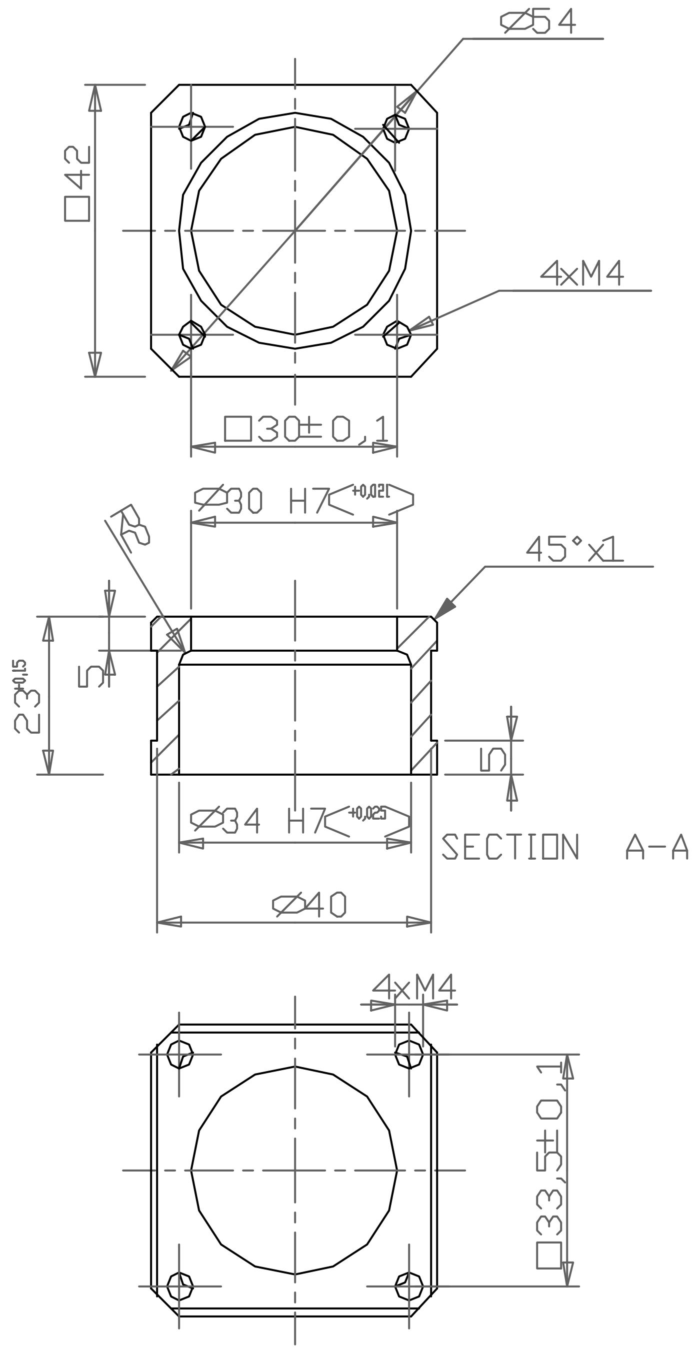
3.12		CIRCLIP D12 DIN471	PART	3
3.13	PM.01.04.00.06	COTTER 1.8X3X15	PART	1
3.14		DC MOTOR/GEAR	PART	1
3.15	PM.01.04.00.19	INSERT FOR O-RING	PART	1
3.16	PM.01.03.00.11	MOTOR SHELL CL.	PART	1
3.17		NUT M12X0.5 H=4	PART	1
3.18		SCREW ISO-M4 X 6	PART	8
3.19		SCREW ISO-M4 X 12	PART	12
3.20		SCREW ISO-M4 X 16	PART	8
3.21	PM.01.04.00.33	TOOTHED BUSHING	PART	1
4.	PM.01.05.00.00	LOWERARM SEGMENT	ASSEMBLY	1
4.1		A.S. SCREW	ASSEMBLY	6
4.2	PM.01.05.01.00	INSIDE BUSHING	ASSEMBLY	1
4.3		SCREW M4X12 & WASHER	ASSEMBLY	4
4.4	PM.01.05.00.28	A.S. CAP	PART	1
4.5	PM.01.05.00.01	A.S. CONSOLE	PART	1
4.6	PM.01.05.00.13	ADJUSTING SCREW	PART	1
4.7		ANGULAR SENSOR	PART	2
4.8		BEARING N 10XN 26X 8	PART	2
4.9	PM.01.05.00.19	BEARING AXLE	PART	1
4.10	PM.01.05.00.26	BEARING CAP	PART	1
4.11	PM.01.05.00.36	BEARING CAP	PART	1
4.12		BEARING D15XD32X9	PART	1
4.13		BEARING D8XD19X6	PART	2
4.14		CIRCLIP D10	PART	1
4.15		CIRCLIP D19	PART	1
4.16	PM.01.05.00.17	CONICAL GEAR	PART	1
4.17	PM.01.05.00.22	CONICAL GEAR II	PART	1
4.18	PM.01.04.00.06	COTTER 1.8X3X15	PART	1
4.19	PM.01.05.00.21	COTTER 3X2,5X15	PART	1
4.20		DC BRAKE	PART	1
4.21		DC MOTOR/GEAR	PART	1
4.22	PM.01.05.00.37	F/T AXLE	PART	1
4.23		F/T SENSOR	PART	1
4.24		HEX. NUT M8X1 H=3.5	PART	1
4.25	PM.01.05.00.16	LOWERARM FORK	PART	1
4.26	PM.01.05.00.12	MOTOR CASING	PART	1
4.27		NUT M12X0.5 H=4	PART	1
4.28	PM.01.05.00.08	OUTER BUSHING	PART	1
4.29		SCREW ISO M3X6	PART	11
4.30		SCREW ISO M3X8	PART	8
4.31		SCREW ISO M3X12	PART	4
4.32		SCREW ISO M4X40	PART	4
4.33		SCREW ISO M6X10	PART	4
4.34	PM.01.05.00.23	SPACER	PART	1
4.35	PM.01.05.00.40	SPACER 1	PART	1
4.36	PM.01.05.00.38	SPACER 2	PART	1
4.37	PM.01.05.00.32	TOOTHED BUSH	PART	1

4.38	PM.01.05.00.42	TOOTHED BUSHING	PART	1
5.	PM.01.04.00.00	SHOULDER	ASSEMBLY	1
5.1		A.S. SCREW	ASSEMBLY	3
5.2		SCREW M4X12 & WASHER	ASSEMBLY	16
5.3	PM.01.04.00.21	A.S. CONSOLE	PART	1
5.4		ANGULAR SENSOR	PART	2
5.5		BEARING N 10XN 26X 8	PART	2
5.6		BEARING N 12XN 28X 8	PART	2
5.7	PM.01.04.00.08	BEARING BUSHING	PART	1
5.8	PM.01.04.00.13	BEARING CASING FOR N 26	PART	1
5.9	PM.01.04.00.32	BEARING INSERT	PART	1
5.10	PM.01.04.00.25	BEARING INSERT FOR 28X8	PART	1
5.11	PM.01.04.00.05	BUSH	PART	1
5.12	PM.01.04.00.15	BUSH-AXLE	PART	1
5.13	PM.01.04.00.34	BUSHING II	PART	1
5.14	PM.01.04.00.37	CENTER BUSHING	PART	3
5.15		CIRCLIP D10	PART	1
5.16		CIRCLIP D28	PART	2
5.17		CIRCLIP D12 DIN471	PART	2
5.18	PM.01.04.00.31	CONSOLE III	PART	1
5.19	PM.01.04.00.26	CONSOLE MOTOR	PART	1
5.20	PM.01.04.00.06	COTTER 1.8X3X15	PART	2
5.21	PM.01.04.00.12	CROSS YOKE	PART	1
5.22		DC MOTOR/GEAR	PART	2
5.23	PM.01.04.01.00	FORK 1	PART	1
5.24	PM.01.04.02.00	FORK 2	PART	1
5.25	PM.01.04.00.19	INSERT FOR O-RING	PART	1
5.26	PM.01.04.00.36	NUT SPECIAL	PART	1
5.27	PM.01.04.00.23	PULLEY	PART	1
5.28	PM.01.04.00.39	PULLEY BUSHING	PART	1
5.29		RING D26X0,5	PART	1
5.30		SCREW ISO M4X10	PART	4
5.31		SCREW ISO M6X10	PART	4
5.32		SCREW ISO-M4 X 6	PART	12
5.33	PM.01.04.00.16	SPACER	PART	1
5.34		TOOTHED BELT PULLEY	PART	2
5.35	PM.01.04.00.33	TOOTHED BUSHING	PART	1
6.	PM.01.06.00.00	UPPERARM	ASSEMBLY	1
6.1		A.S. SCREW	ASSEMBLY	4
6.2	PM.01.05.00.01	A.S. CONSOLE	PART	1
6.3	PM.01.06.00.19	ADJUSTMENT SCREW	PART	1
6.4		ANGULAR SENSOR	PART	1
6.5		BEARING N 10XN 26X 8	PART	2
6.6	PM.01.05.00.36	BEARING CAP	PART	1
6.7	PM.01.06.00.12	CENTER PIN	PART	1
6.8		CIRCLIP D10	PART	1
6.9		DC BRAKE	PART	1
6.10	PM.01.06.00.09	F/T AXLE	PART	1

6.11		F/T SENSOR	PART	1
6.12	PM.01.06.00.10	INSIDE CASING	PART	1
6.13	PM.01.06.00.01	OUTER CASING	PART	1
6.14		SCREW ISO M3X6	PART	4
6.15		SCREW ISO M3X8	PART	10
6.16		SCREW ISO M4X40	PART	4
6.17	PM.01.05.00.40	SPACER 1	PART	1
6.18	PM.01.05.00.38	SPACER 2	PART	1
6.19	PM.01.05.00.42	TOOTHED BUSHING	PART	1

3.2 Parts and assembly drawings





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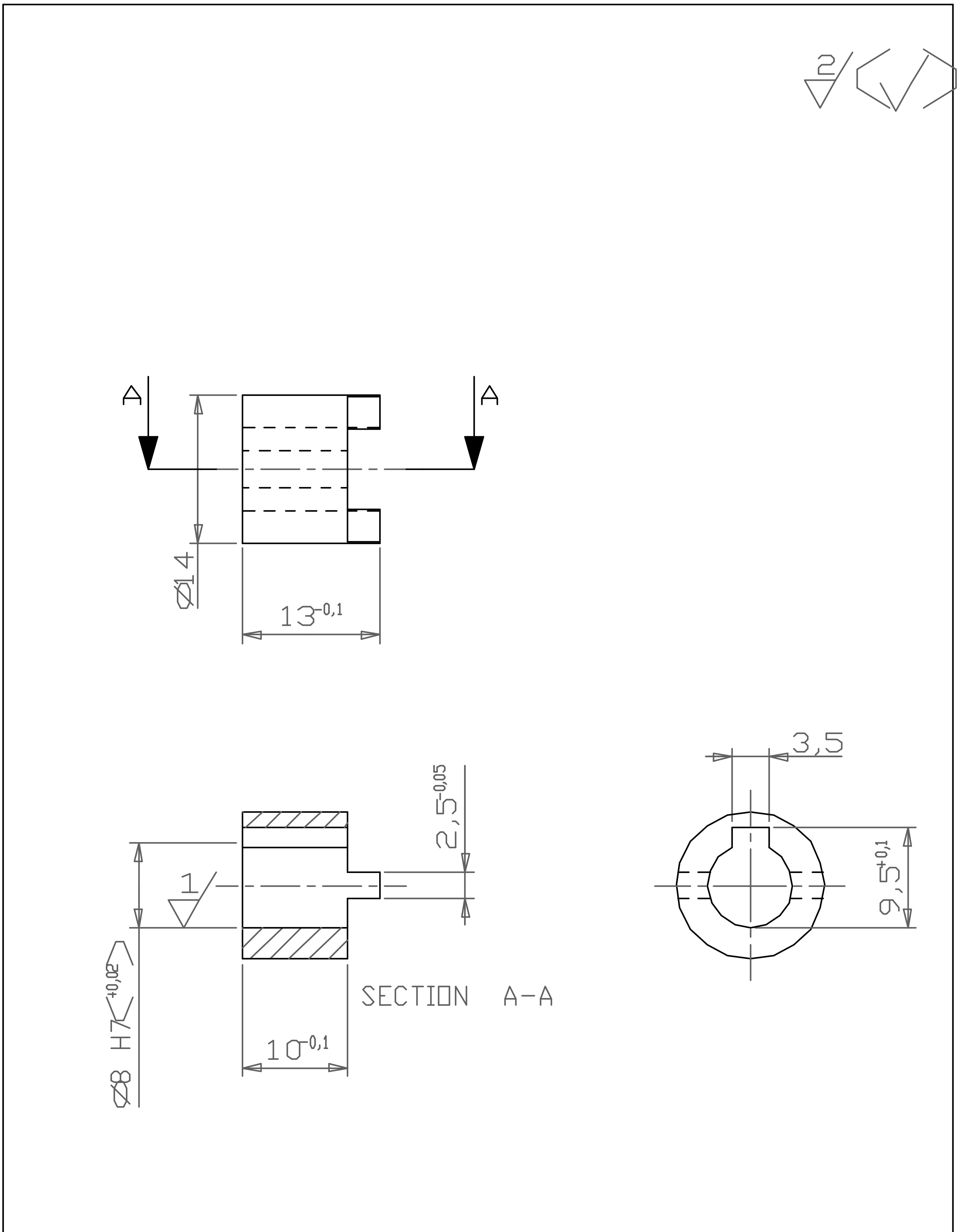

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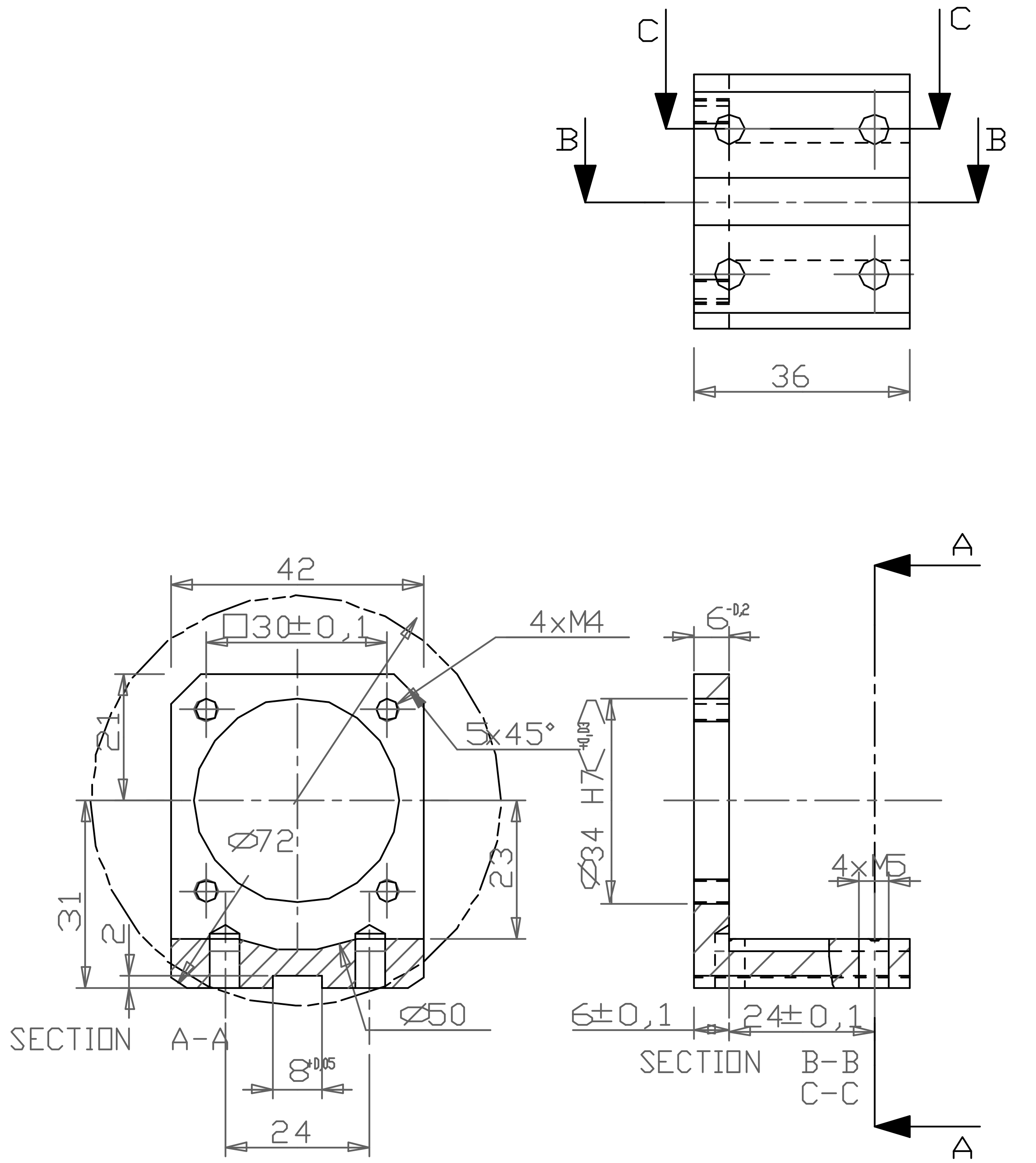

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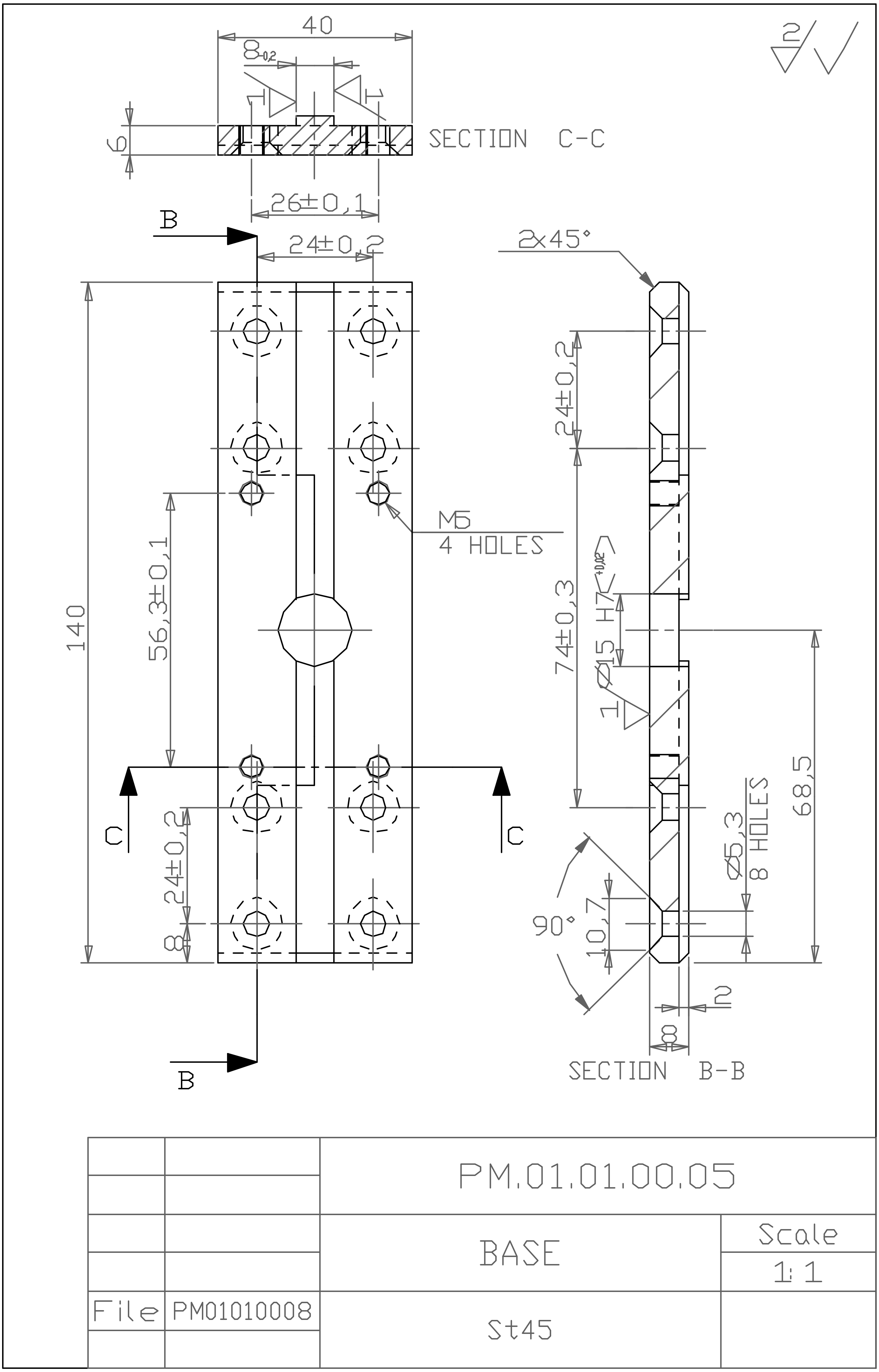
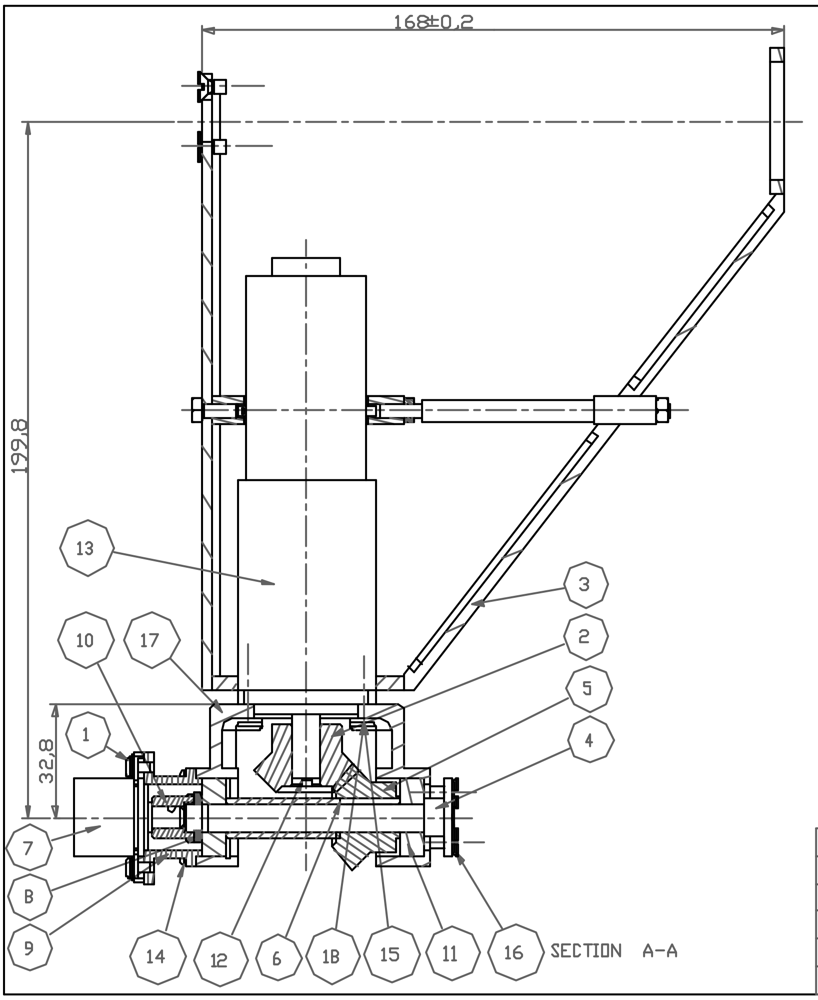
File	PM01010004	Al	



40
8-0,2
6
SECTION C-C
26±0,1
B
24±0,2
2x45°
140
56,3±0,1
M5
4 HOLES
24±0,2
74±0,3
1 Ø15 H7(+0,02)
C
C
24±0,2
8
90°
10,7
Ø5,3
8 HOLES
68,5
2
8
B
SECTION B-B
PM.01.01.00.05
BASE
Scale
1:1
File
PM01010008
St45



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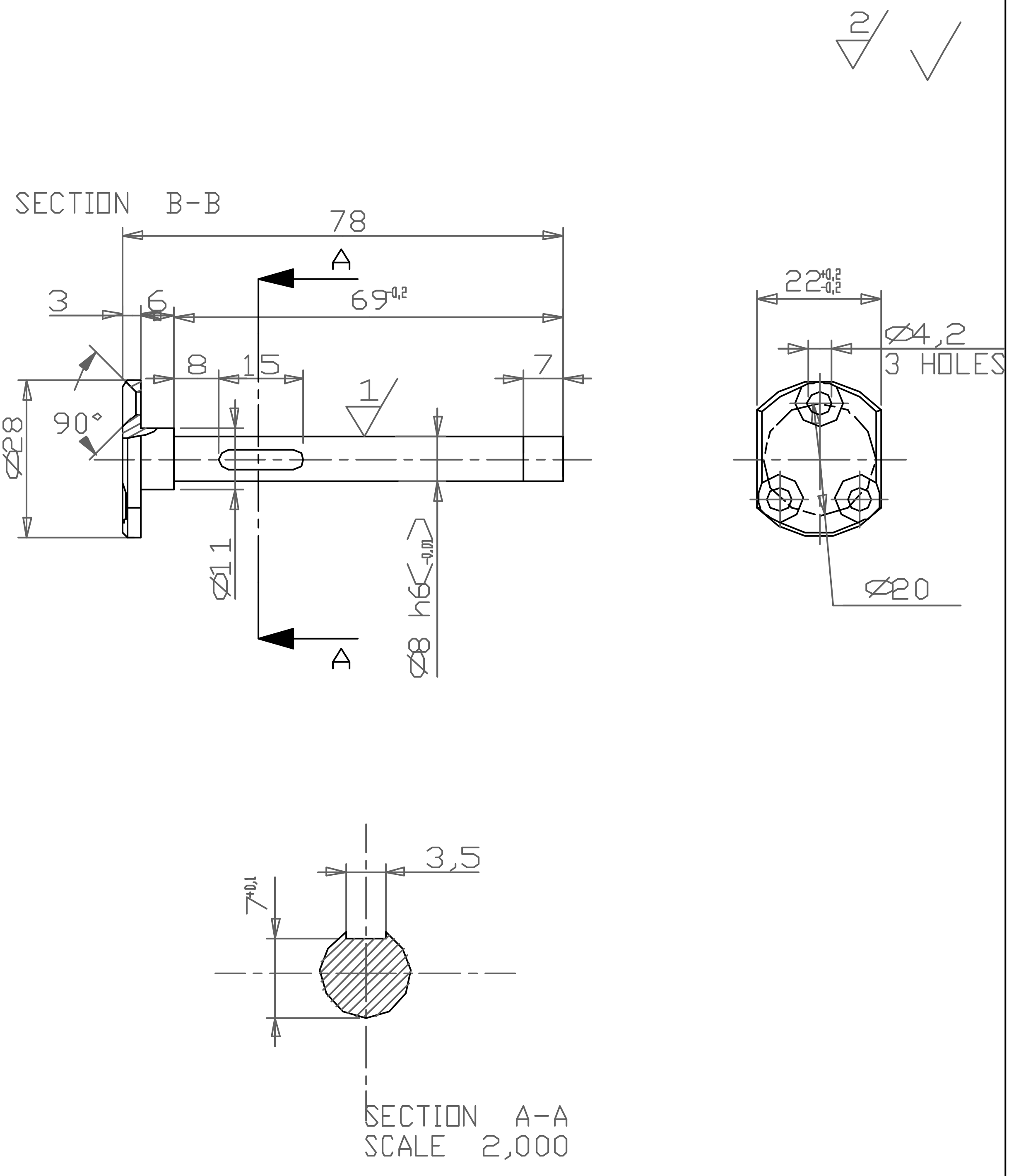
		Scale 1 : 1
File	PM01020000	Sheet: 1 of 3

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
1		A.S. SCREW	ASSEMBLY	4
		A.S. BRACKET	PART	1
		Screw M3 x 5 (ISO)	PART	1
		Washer M3	PART	1
2	PM.01.02.00.02	CONICAL GEAR	PART	1
3	PM.01.02.01.00	FORK	ASSEMBLY	1
	PM.01.02.01.03	FORK ARM LEFT	PART	1
	PM.01.02.01.11	FORK ARM RIGHT	PART	1
	PM.01.02.01.02	FORK BASE	PART	1
	PM.01.02.01.08	FORK EAR	PART	1
		Nut M4	PART	2
	PM.01.02.01.10	PEG	PART	1
	PM.01.02.01.06	RING	PART	1
		Screw ISO M4 x 10	PART	1
	PM.01.02.01.07	STUD BOLT	PART	1
4	PM.01.02.00.04	BEARING AXLE	PART	1
5	PM.01.02.00.05	CONICAL GEAR II	PART	1

		PM.01.02.00.00
		CLAVICLE JOINT
		Scale 1:1
File	PM01020000	Sheet: 2 of 3

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
6	PM.01.02.00.06	SPACER	PART	1
7		ANGULAR SENSOR	PART	1
8	PM.01.02.00.08	NUT M8 SPECIAL	PART	1
9	PM.01.02.00.09	A.S. CONSOLE	PART	1
10	PM.01.02.00.10	TOOTHED BUSHING	PART	1
11		BEARING 8x22x7	PART	2
12	PM.01.04.00.06	COTTER 1.8x3x15	PART	1
13		DC MOTOR/GEAR	PART	1
14		SCREW ISO M3x8	PART	4
15		SCREW ISO M4x20	PART	4
16		Screw ISO-M4 x 6	PART	6
17	PM.01.02.00.17	SHOULDER FORK	PART	1
18		WASHER ISO M4	PART	4

		PM.01.02.00.00
		CLAVICLE JOINT
		Scale 1:1
File	PM01020000	Sheet: 3 of 3



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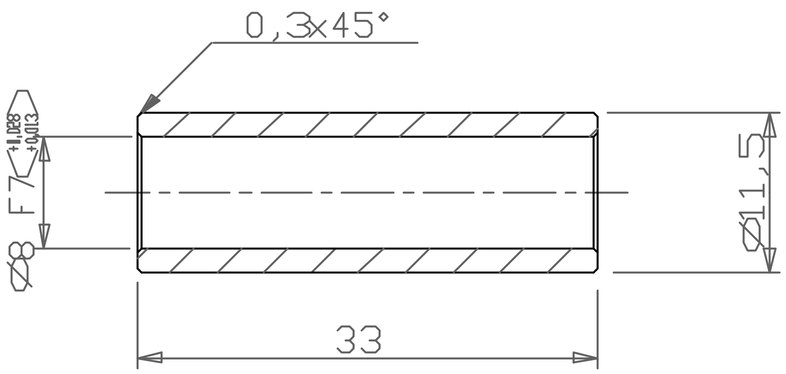

SECTION A-A
SCALE 2,000

* Dim 33 is confirmed after assembly of conical gear and bearings

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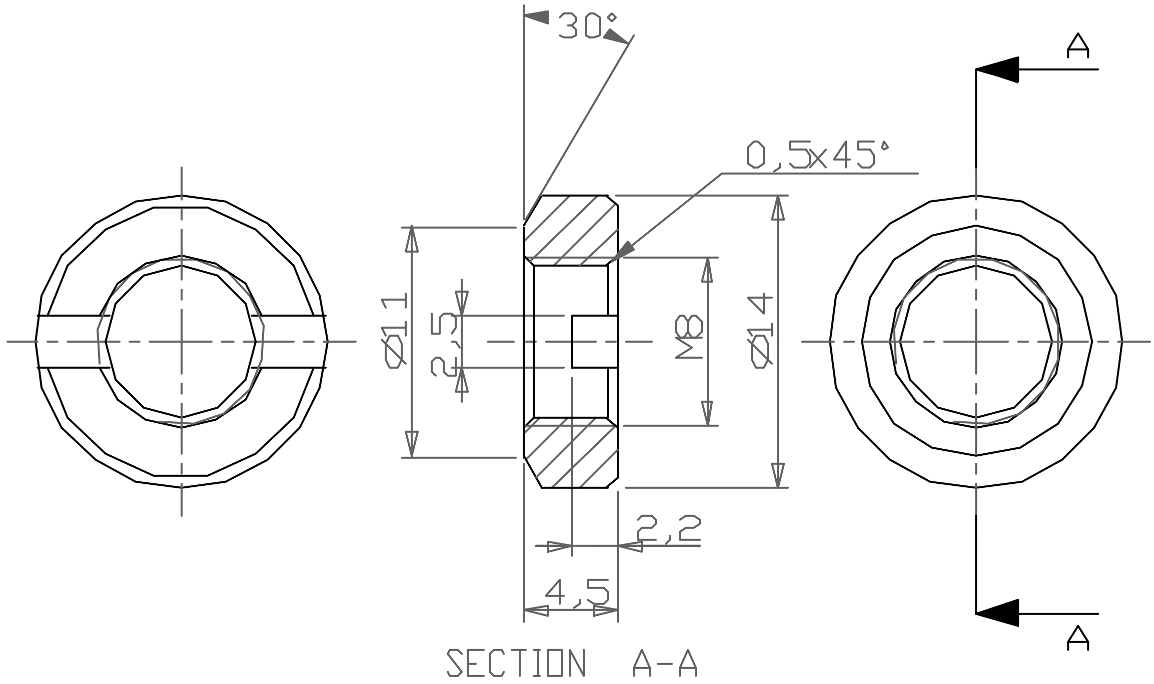

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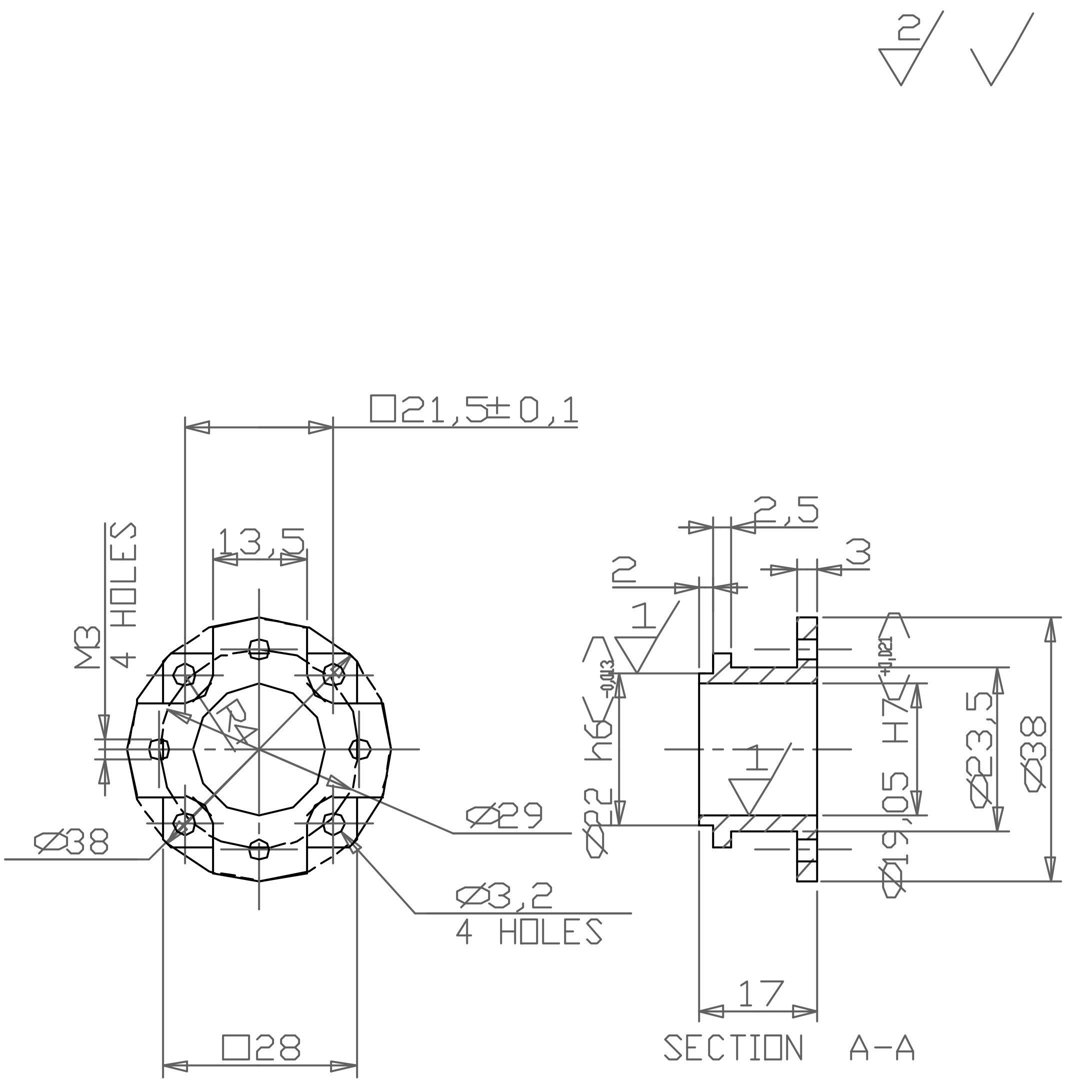

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		A.S. CONSOLE	Scale
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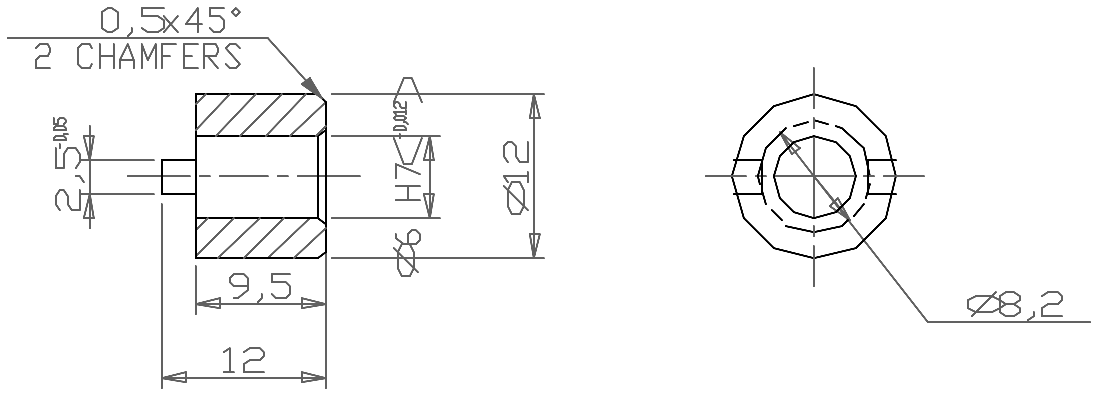

SECTION A-A

		PM.01.02.00.10	
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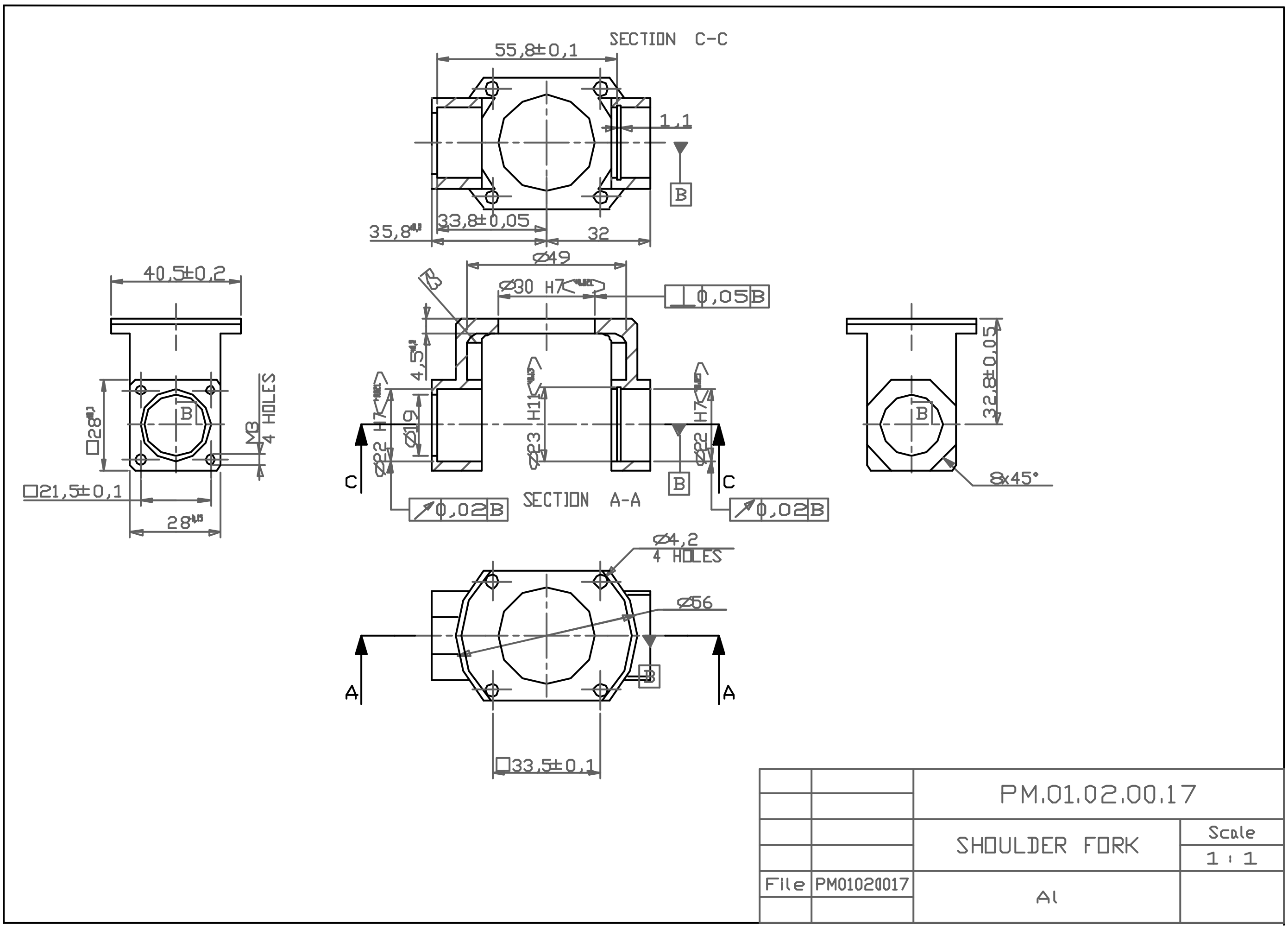
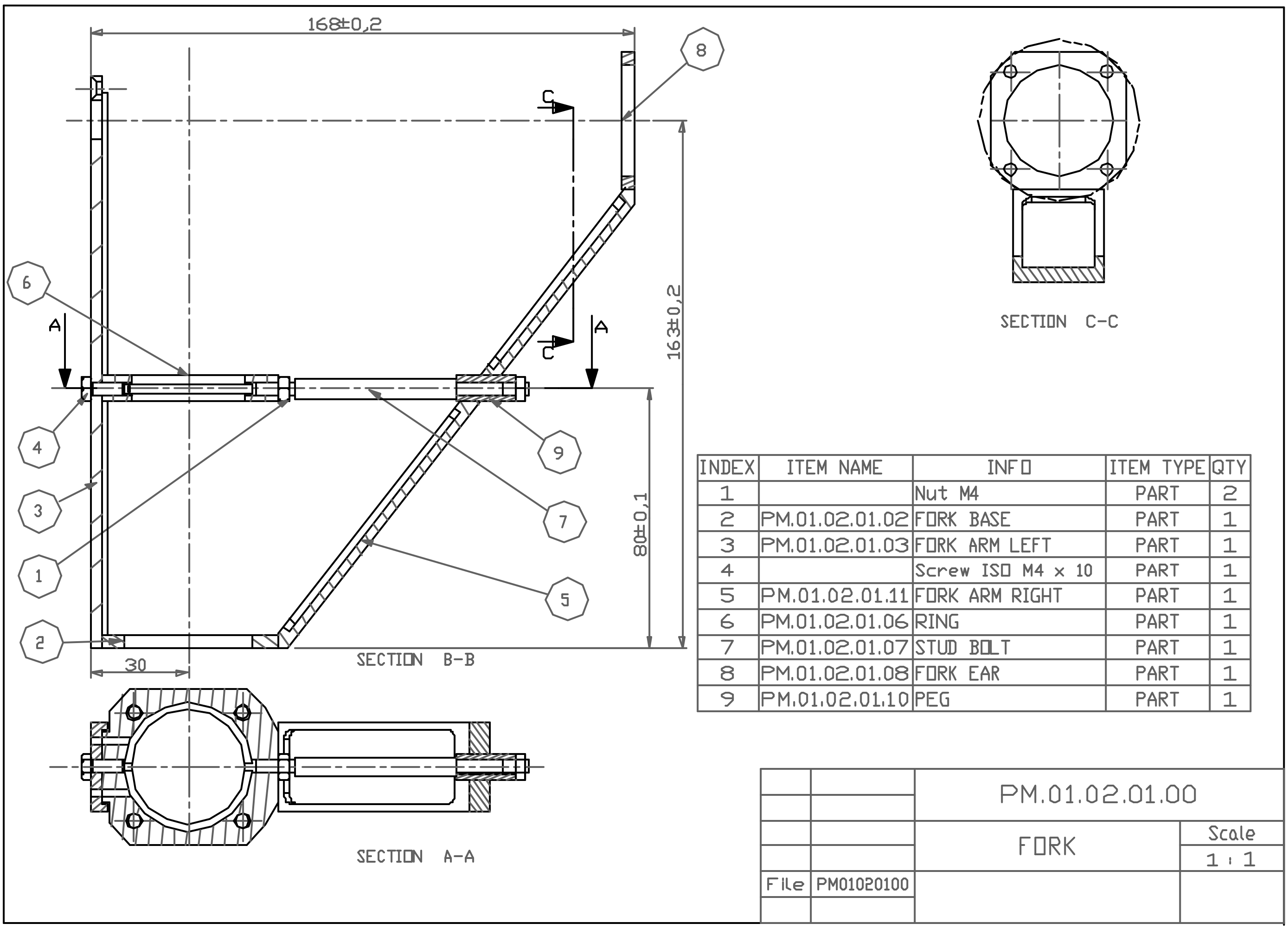
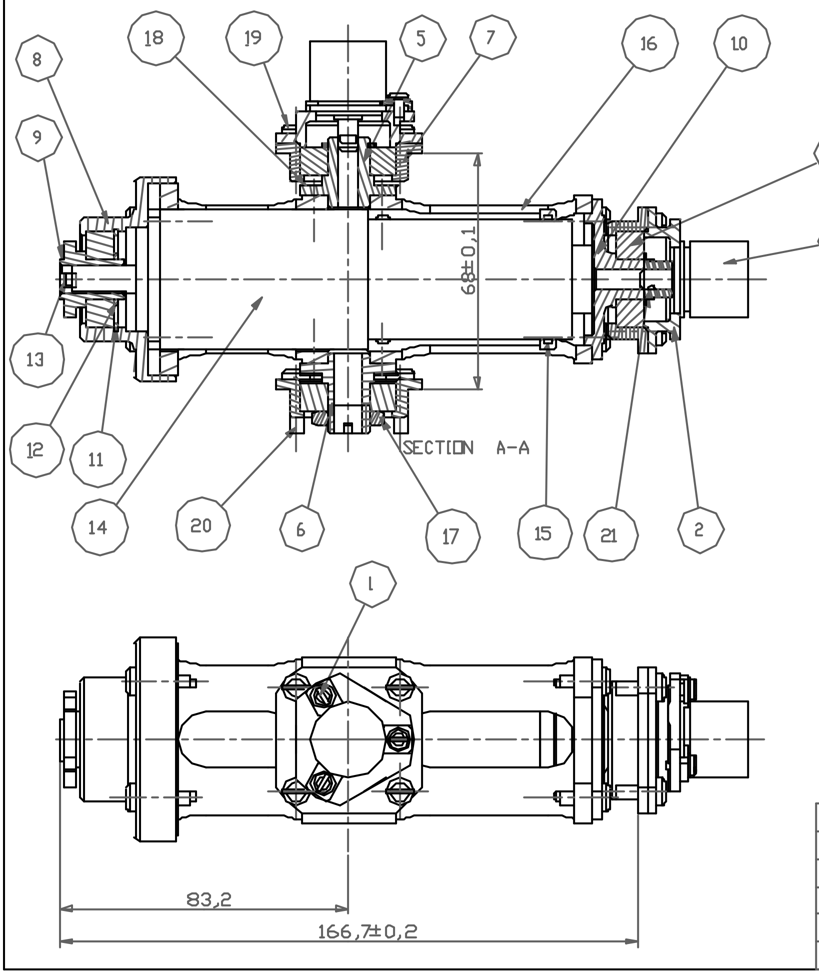
File	PM01020010	Al	





INDEX	ITEM NAME	INFO	ITEM TYPE	QTY
1		Nut M4	PART	2
2	PM.01.02.01.02	FORK BASE	PART	1
3	PM.01.02.01.03	FORK ARM LEFT	PART	1
4		Screw ISO M4 x 10	PART	1
5	PM.01.02.01.11	FORK ARM RIGHT	PART	1
6	PM.01.02.01.06	RING	PART	1
7	PM.01.02.01.07	STUD BOLT	PART	1
8	PM.01.02.01.08	FORK EAR	PART	1
9	PM.01.02.01.10	PEG	PART	1



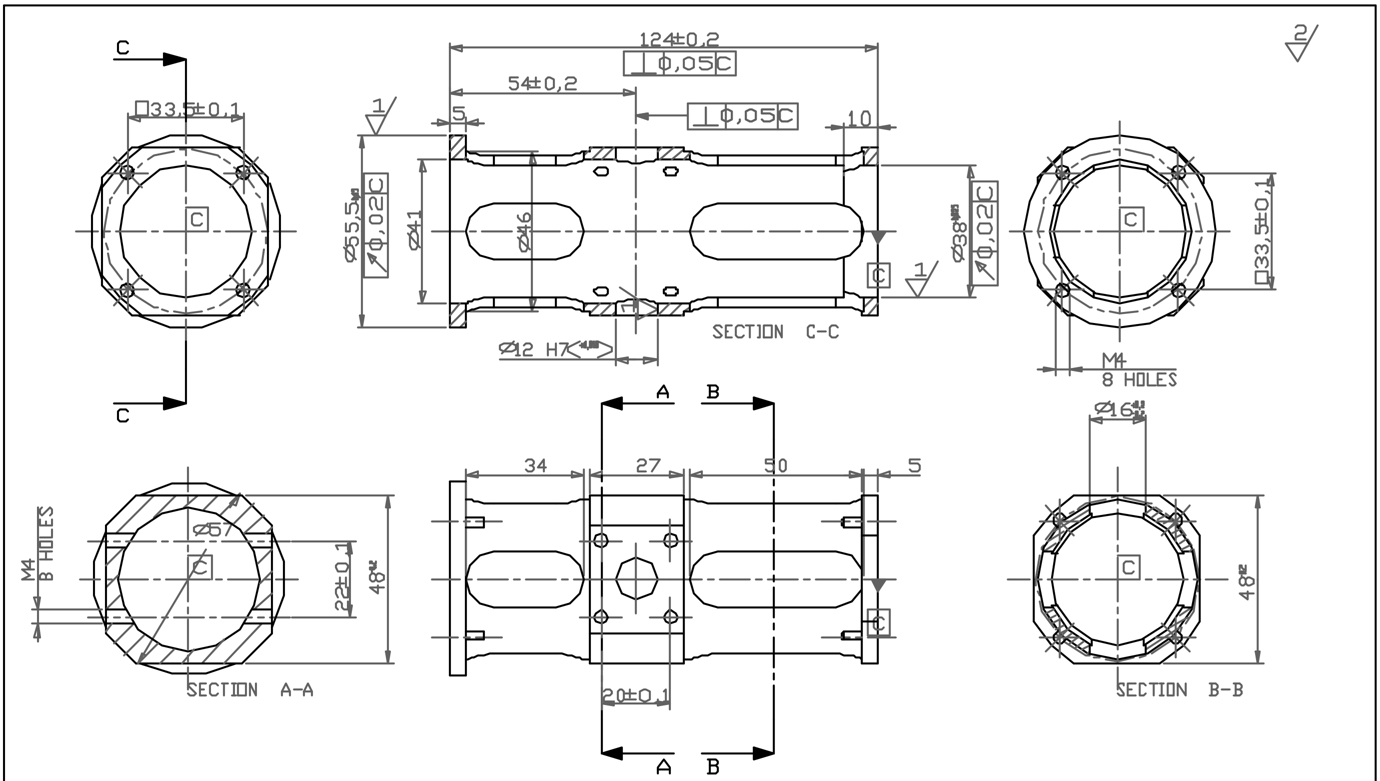
INDEX	Component Name	Comp. Type	Qty.	Info
1		ASSEMBLY	6	A.S. SCREW
2	PM.01.03.00.12	PART	2	A.S. SUPPORT
3		PART	2	ANGULAR SENSOR
4		PART	4	BEARING Ø12xØ28x8
5	PM.01.03.00.14	PART	1	BEARING AXLE I
6	PM.01.03.00.23	PART	1	BEARING AXLE II
7	PM.01.03.00.13	PART	3	BEARING BED
8	PM.01.04.00.08	PART	1	BEARING BUSHING
9	PM.01.04.00.05	PART	1	Bush
10	PM.01.03.00.17	PART	1	CAP
11		PART	1	CIRCLIP D28
12		PART	3	CIRCLIP d12 DIN471
13	PM.01.04.00.06	PART	1	COTTER 1.8x3x15
14		PART	1	DC MOTOR/GEAR
15	PM.01.04.00.19	PART	1	INSERT FOR O-RING
16	PM.01.03.00.11	PART	1	MOTOR SHELL CL.
17		PART	1	NUT M12x0.5 H=4
18		PART	8	Screw ISO-M4 x 6
19		PART	12	Screw ISO-M4 x 12
20		PART	8	Screw ISO-M4 x 16
21	PM,01,04,00,33	PART	1	TOOTHED BUSHING

PM.01.03.00.00

CLAVICLE JOINT

Scale 1 : 1

File PM01030000



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MOTOR SHELL CL.

Scale 1 : 1

File PM01030011

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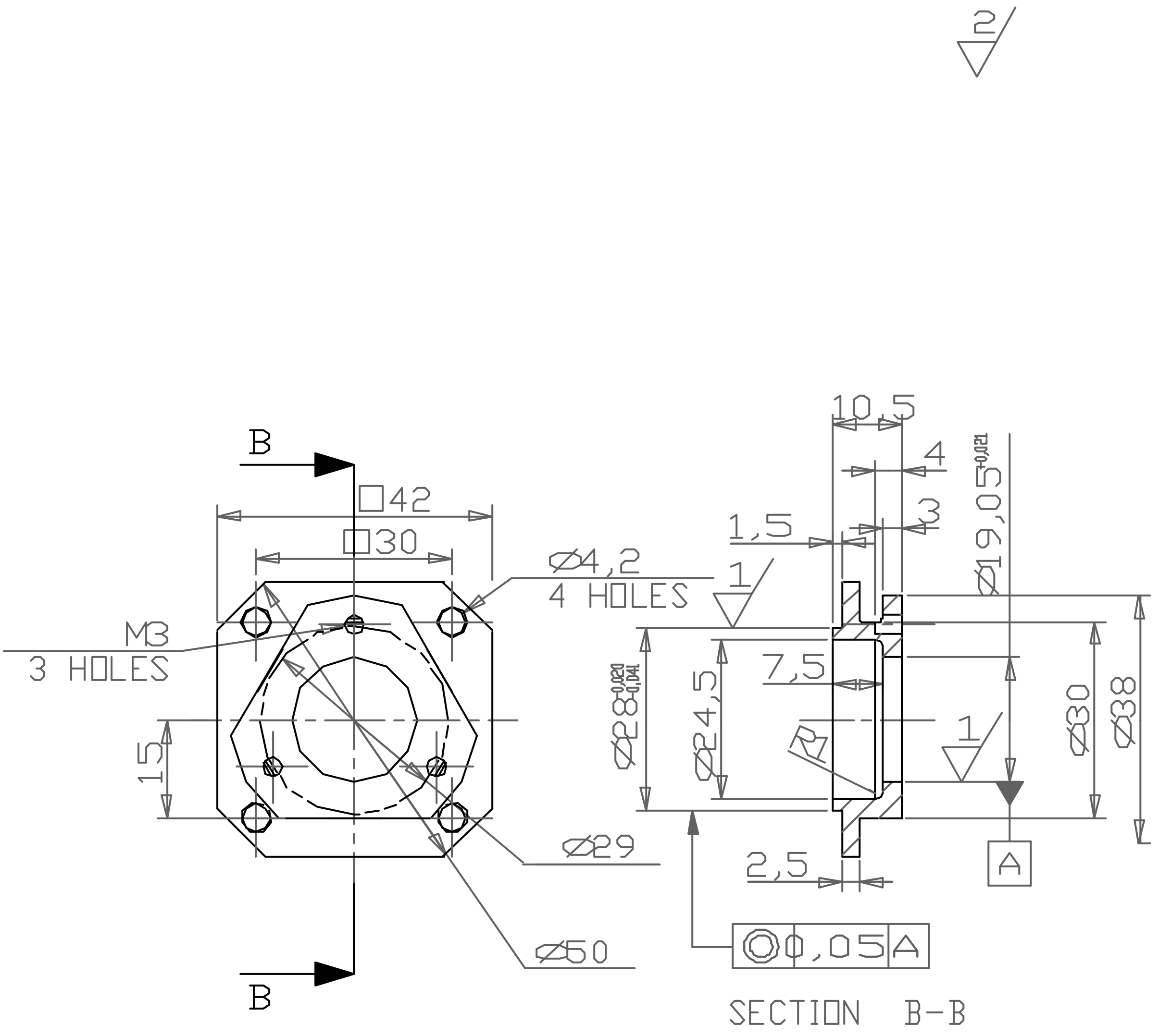

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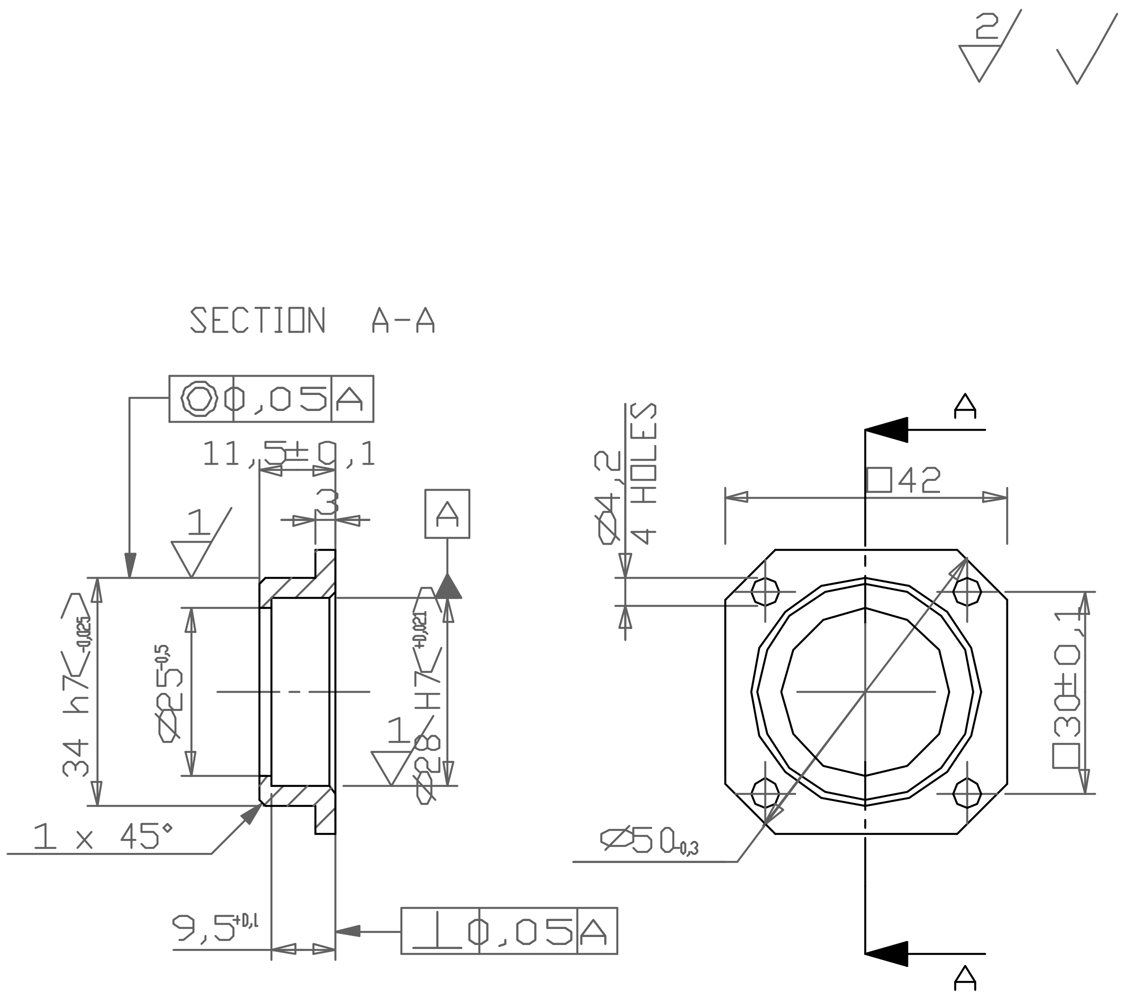

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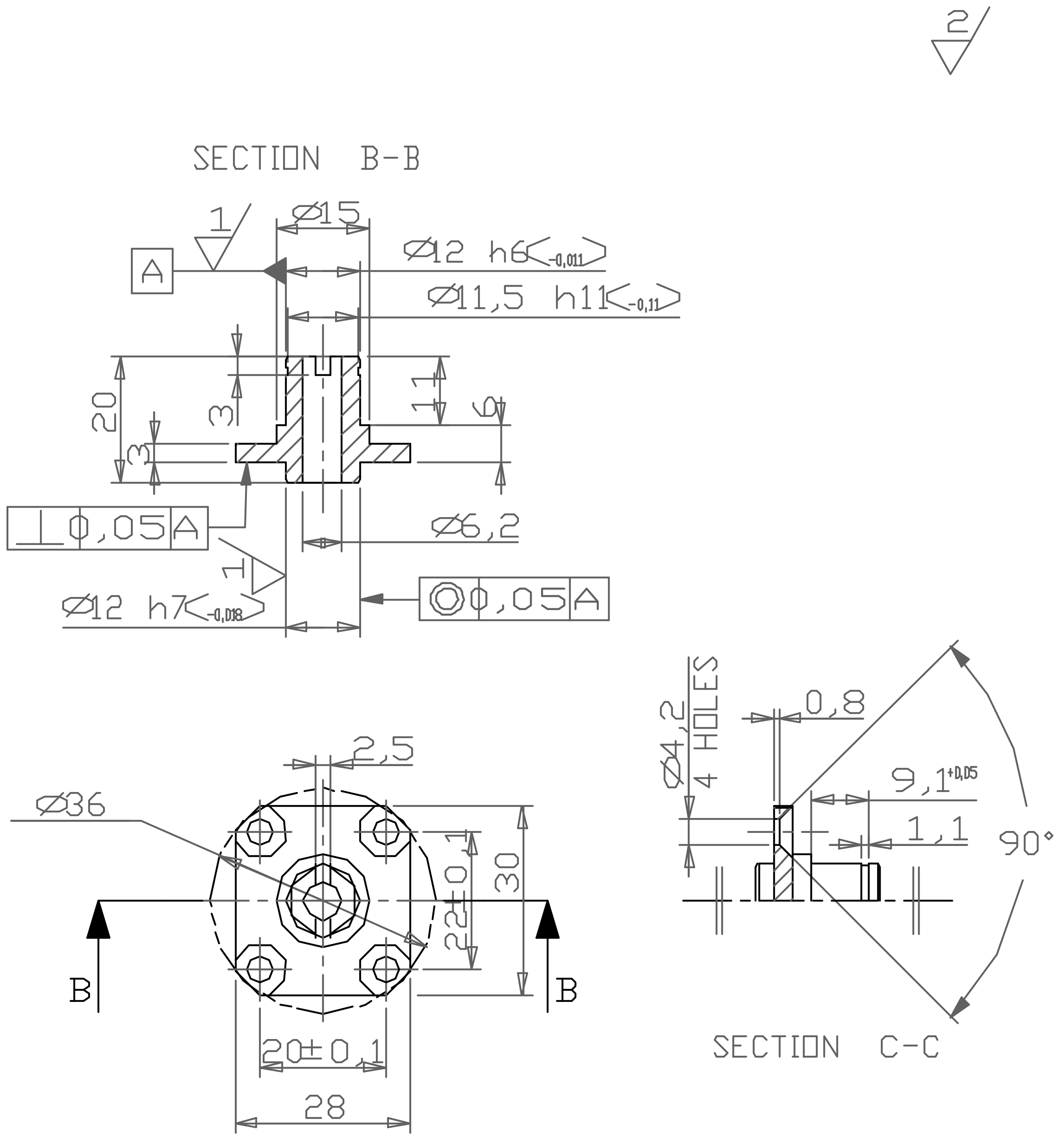
File	PM01030013	Al	



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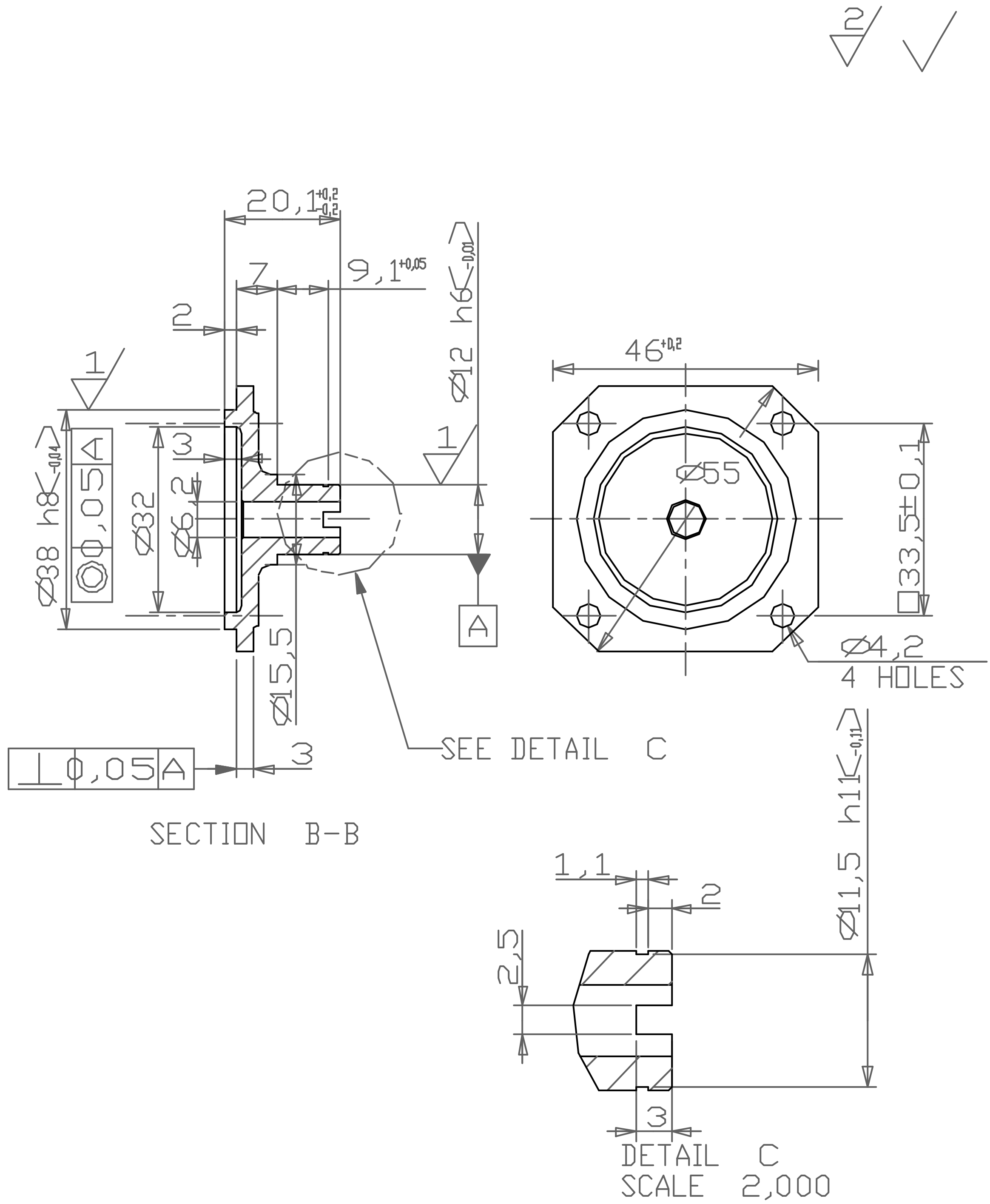
File	PM01030014	Al	



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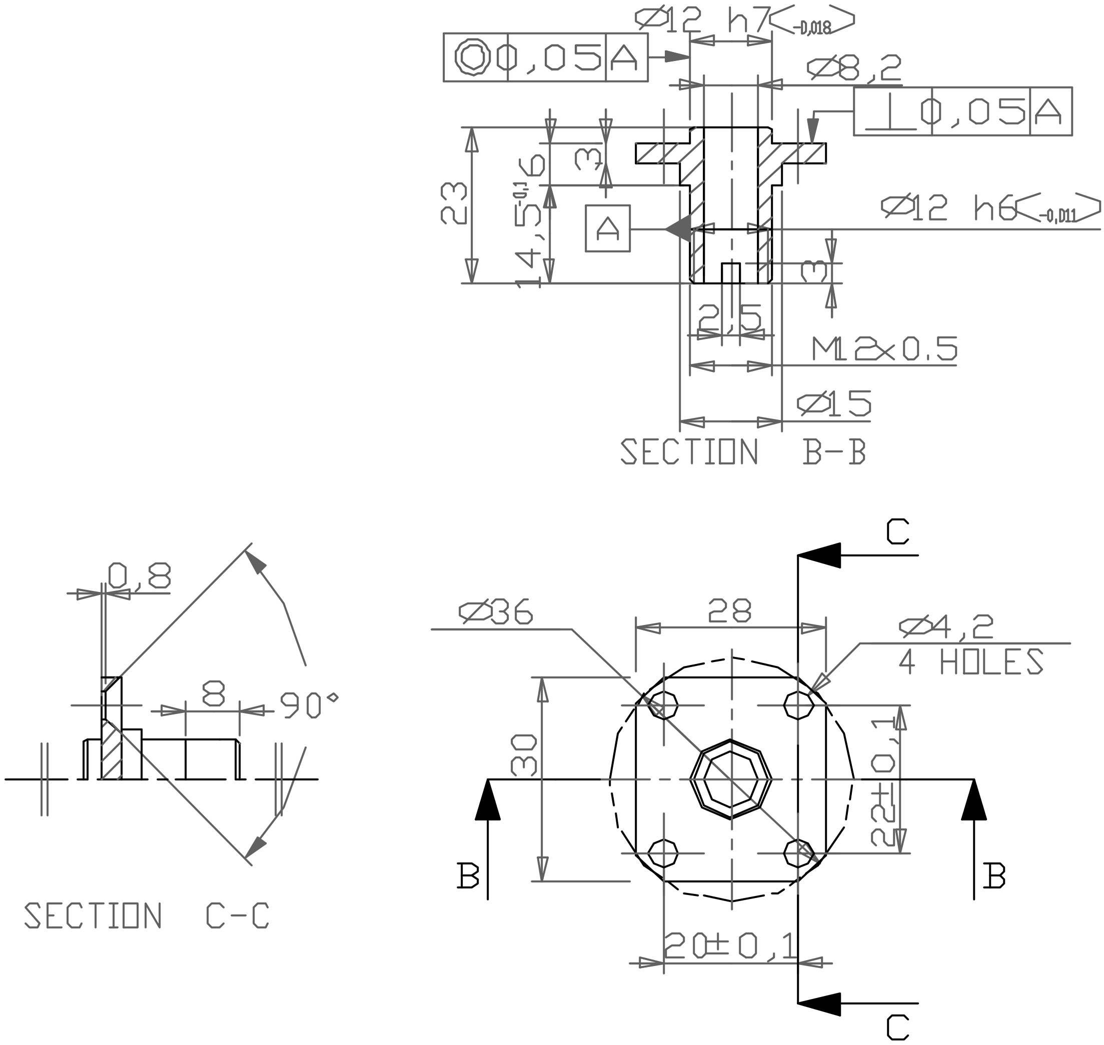

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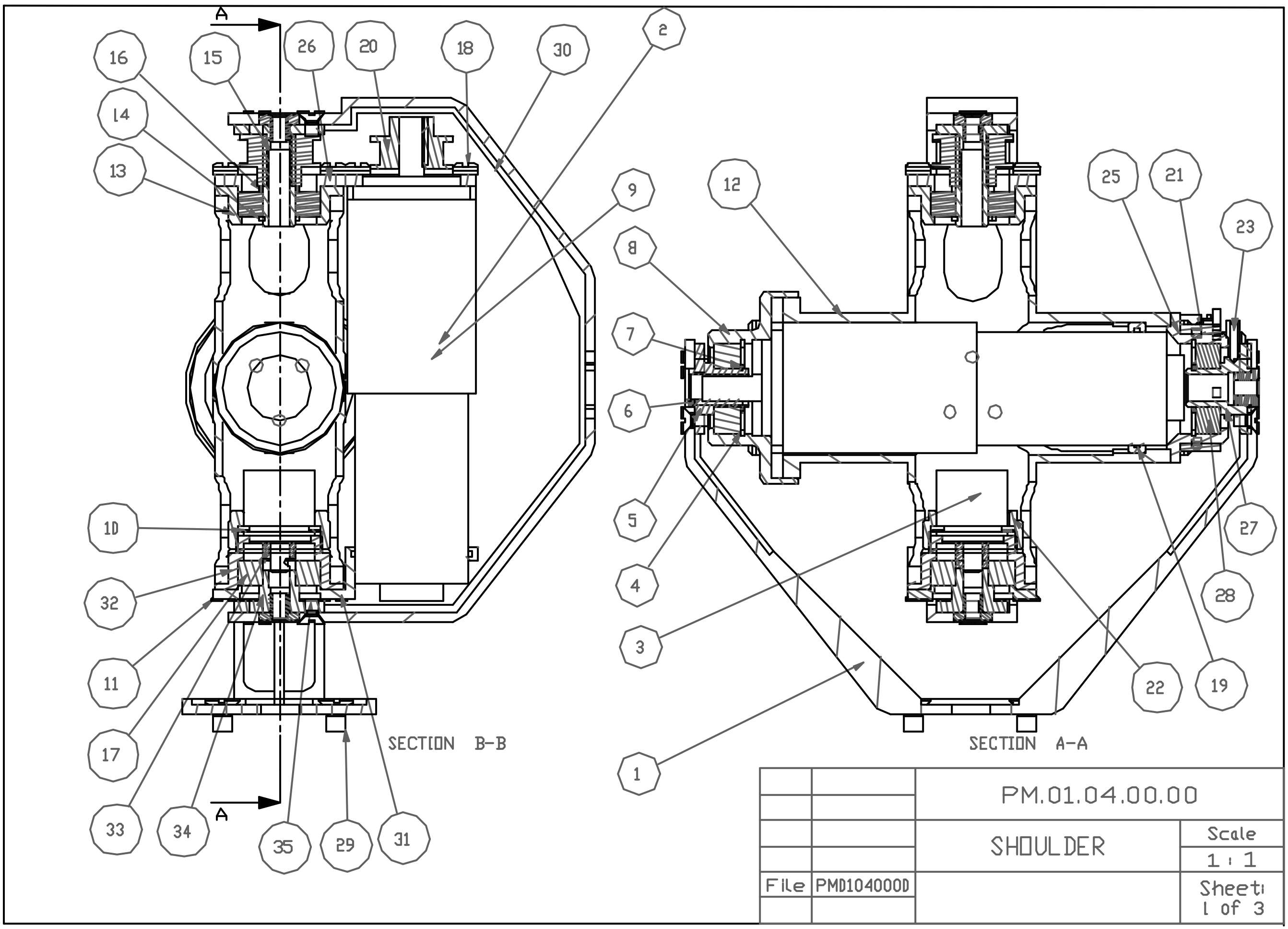
File	PM01030023	St45	



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1	PM.01.04.01.00	FORK 1	PART	1
2		A.S. SCREW	ASSEMBLY	3
		A.S. BRACKET	PART	1
		Screw M3 x 5 (ISO)	PART	1
		Washer M3	PART	1
3		ANGULAR SENSOR	PART	2
4		CIRCLIP D28	PART	2
5	PM.01.04.00.05	Bush	PART	1
6	PM.01.04.00.06	COTTER 1.8x3x15	PART	2
7		CIRCLIP d12 DIN471	PART	2
8	PM.01.04.00.08	BEARING BUSHING	PART	1
9		DC MOTOR/GEAR	PART	2
10		RING D26X0,5	PART	1
11		SCREW ISO M4x10	PART	4
12	PM.01.04.00.12	CROSS YOKE	PART	1
13	PM.01.04.00.13	BEARING CASING FOR Ø26	PART	1
14		CIRCLIP d10	PART	1
15	PM.01.04.00.15	BUSH-AXLE	PART	1
16	PM.01.04.00.16	SPACER	PART	1
17		BEARING Ø10xØ26x8	PART	2
18		SCREW M4x12 & WASHER	ASSEMBLY	16
		Screw ISO-M4 x 12	PART	1
		VASHER ISO M4	PART	1

PM.01.04.00.00

SHOULDER

Scale 1:1

File PM01040000

Sheet: 2 of 3

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
19	PM.01.04.00.19	INSERT FOR O-RING	PART	1
20		TOOTHED BELT PULLEY	PART	2
21	PM.01.04.00.21	A.S. CONSOLE	PART	1
22	PM.01.04.00.36	NUT SPECIAL	PART	1
23	PM.01.04.00.23	PULLEY	PART	1
24	PM.01.04.00.37	CENTER BUSHING	PART	3
25	PM.01.04.00.25	BEARING INSERT FOR 28x8	PART	1
26	PM.01.04.00.26	CONSOLE MOTOR	PART	1
27	PM.01.04.00.39	PULLEY BUSHING	PART	1
28		BEARING Ø12xØ28x8	PART	2
29		SCREW ISO M6x10	PART	4
30	PM.01.04.02.00	FORK 2	PART	1
31	PM.01.04.00.31	CONSOLE III	PART	1
32	PM.01.04.00.32	BEARING INSERT	PART	1
33	PM.01.04.00.33	TOOTHED BUSHING	PART	1
34	PM.01.04.00.34	BUSHING II	PART	1
35		Screw ISO-M4 x 6	PART	12

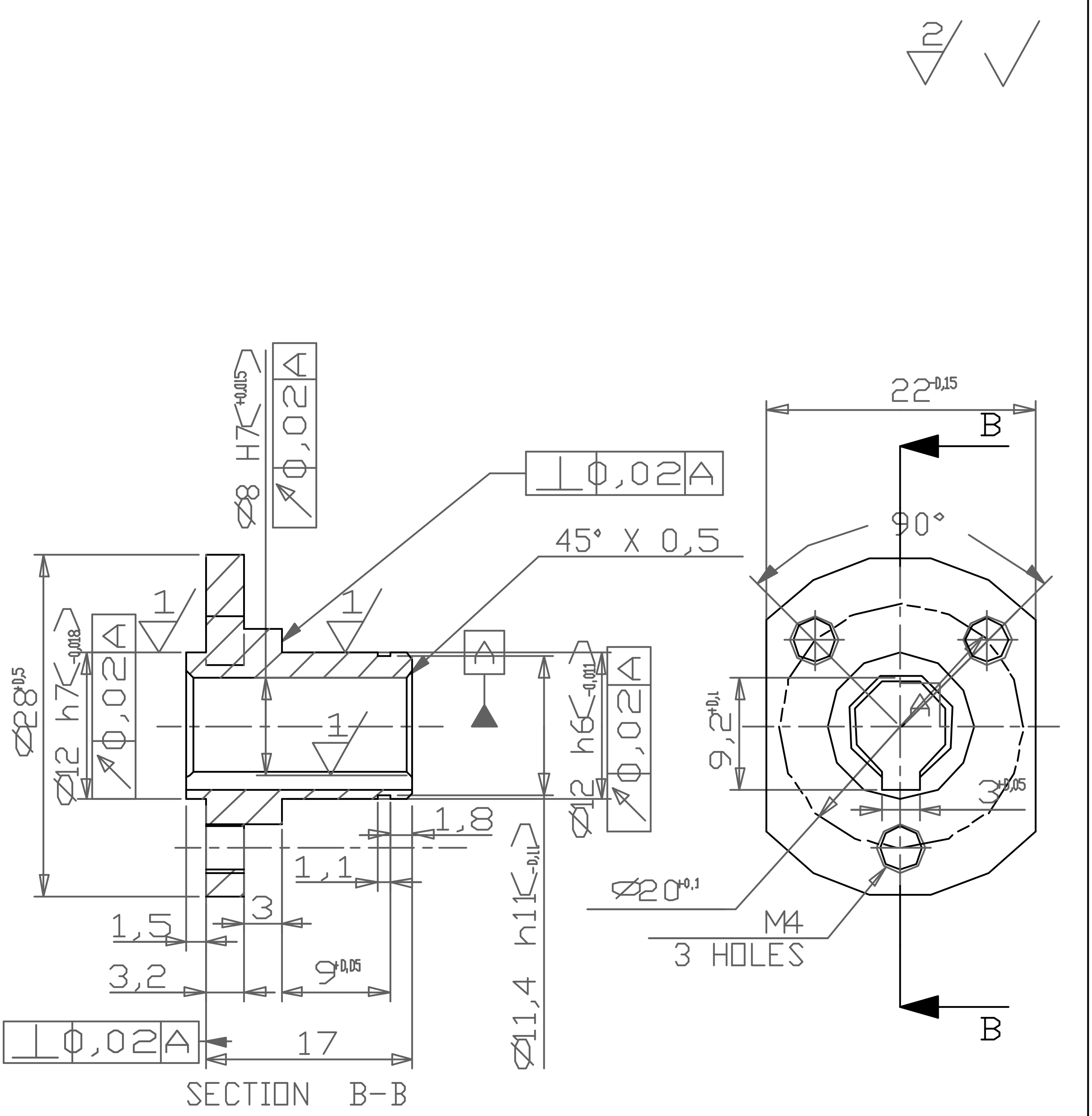
PM.01.04.00.00

SHOULDER

Scale 1:1

File PM0104D000

Sheet: 3 of 3



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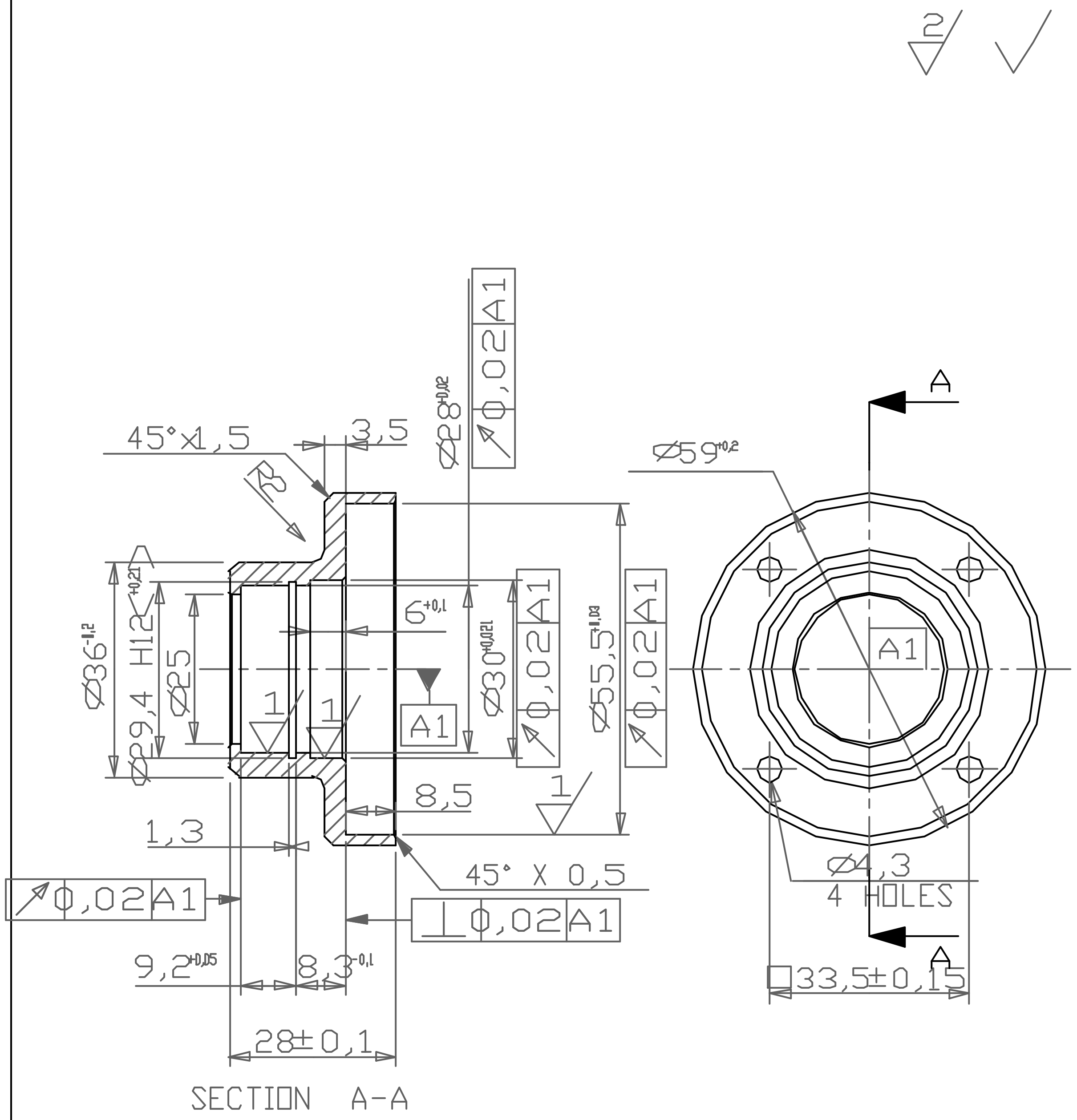

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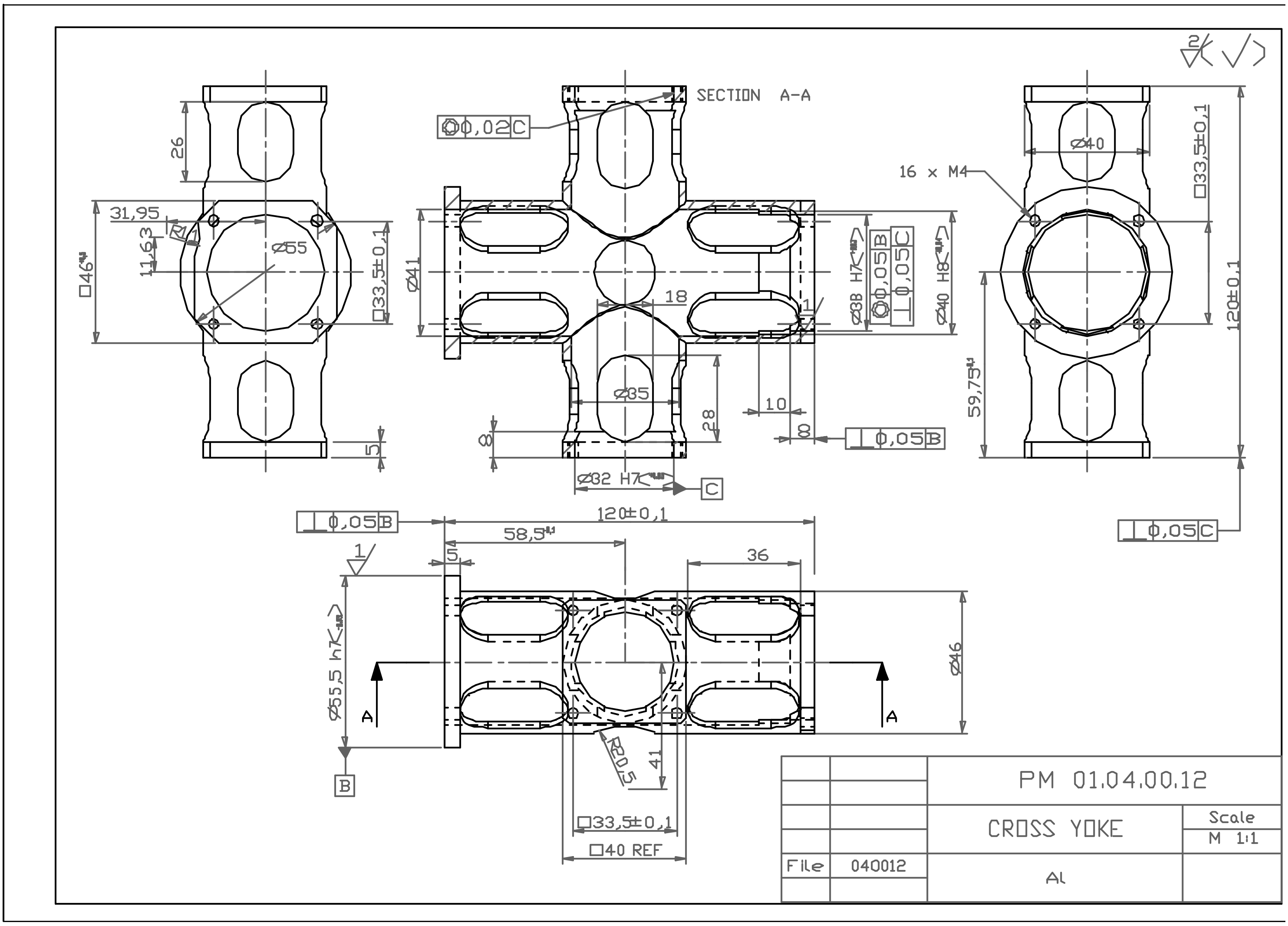
SECTION A-A
16 x M4
PM 01.04.00.12
CROSS YOKE
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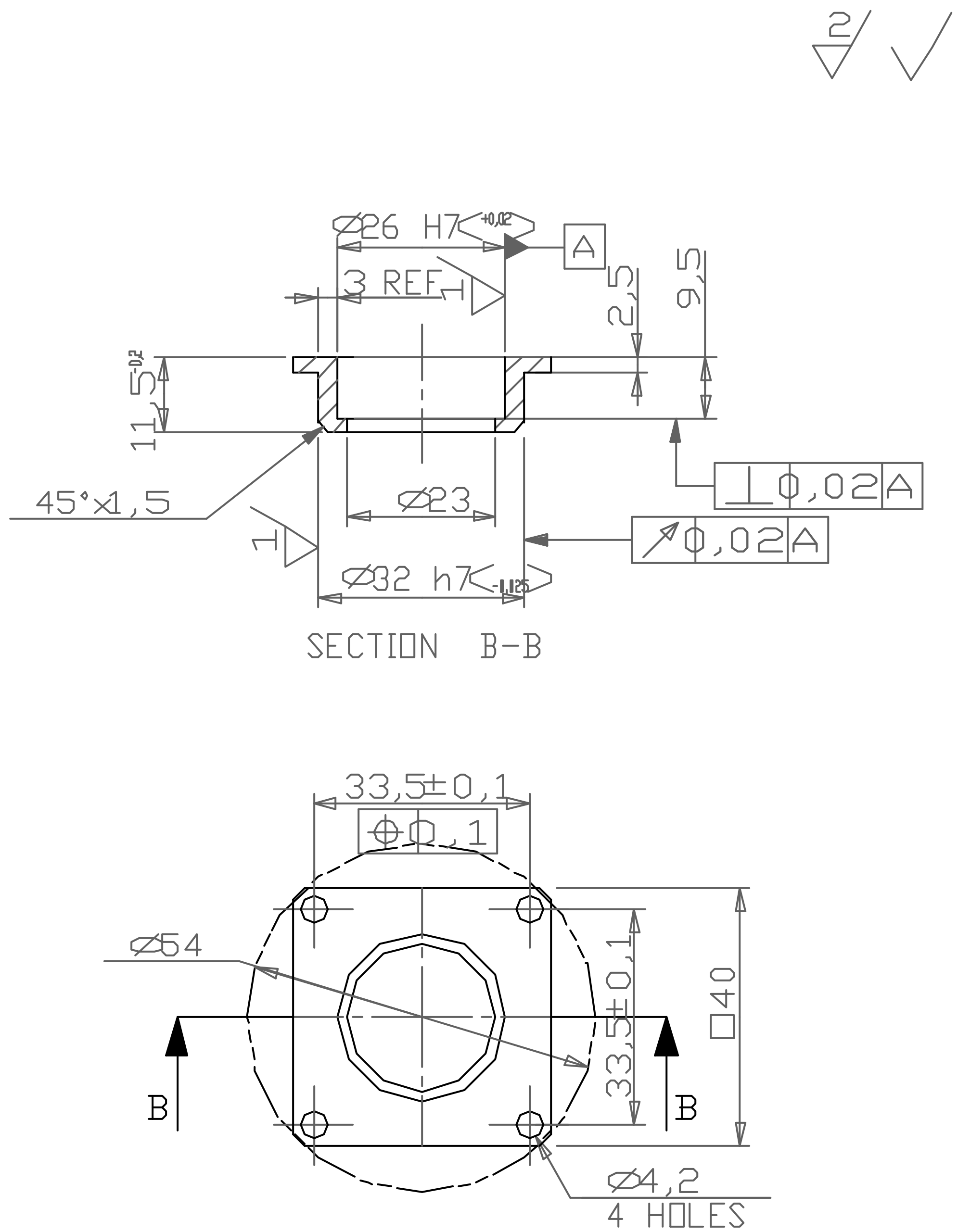
File
040012
AL



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		BEARING CASING FOR ø26	Scale
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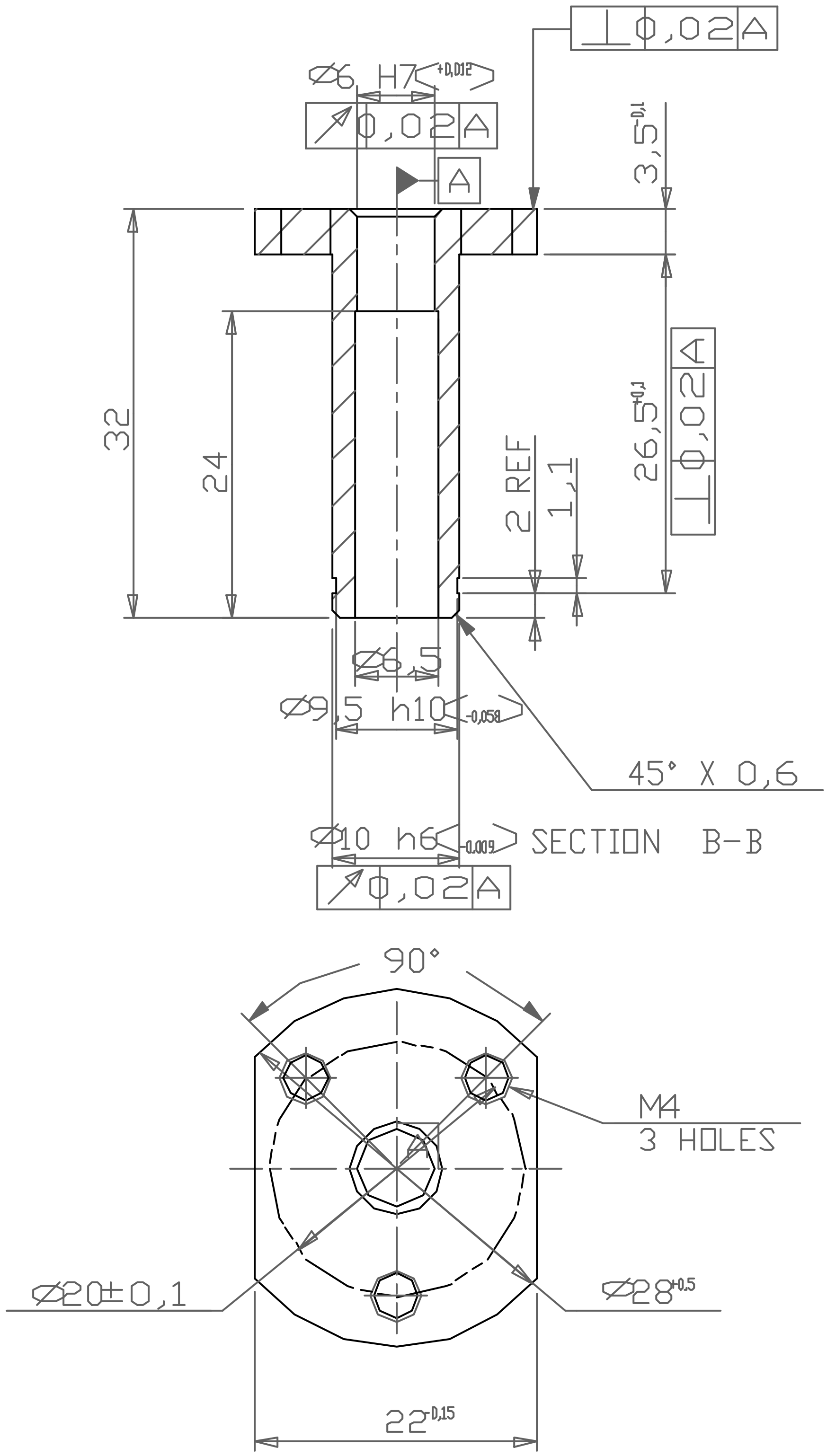

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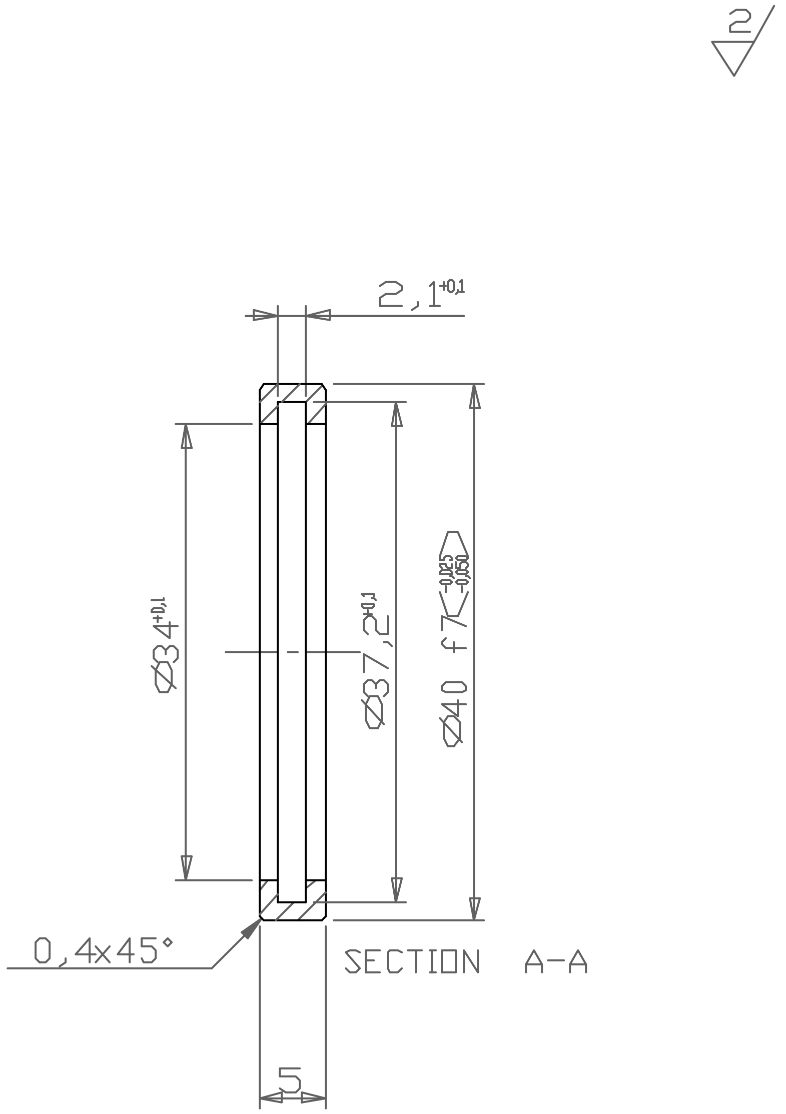

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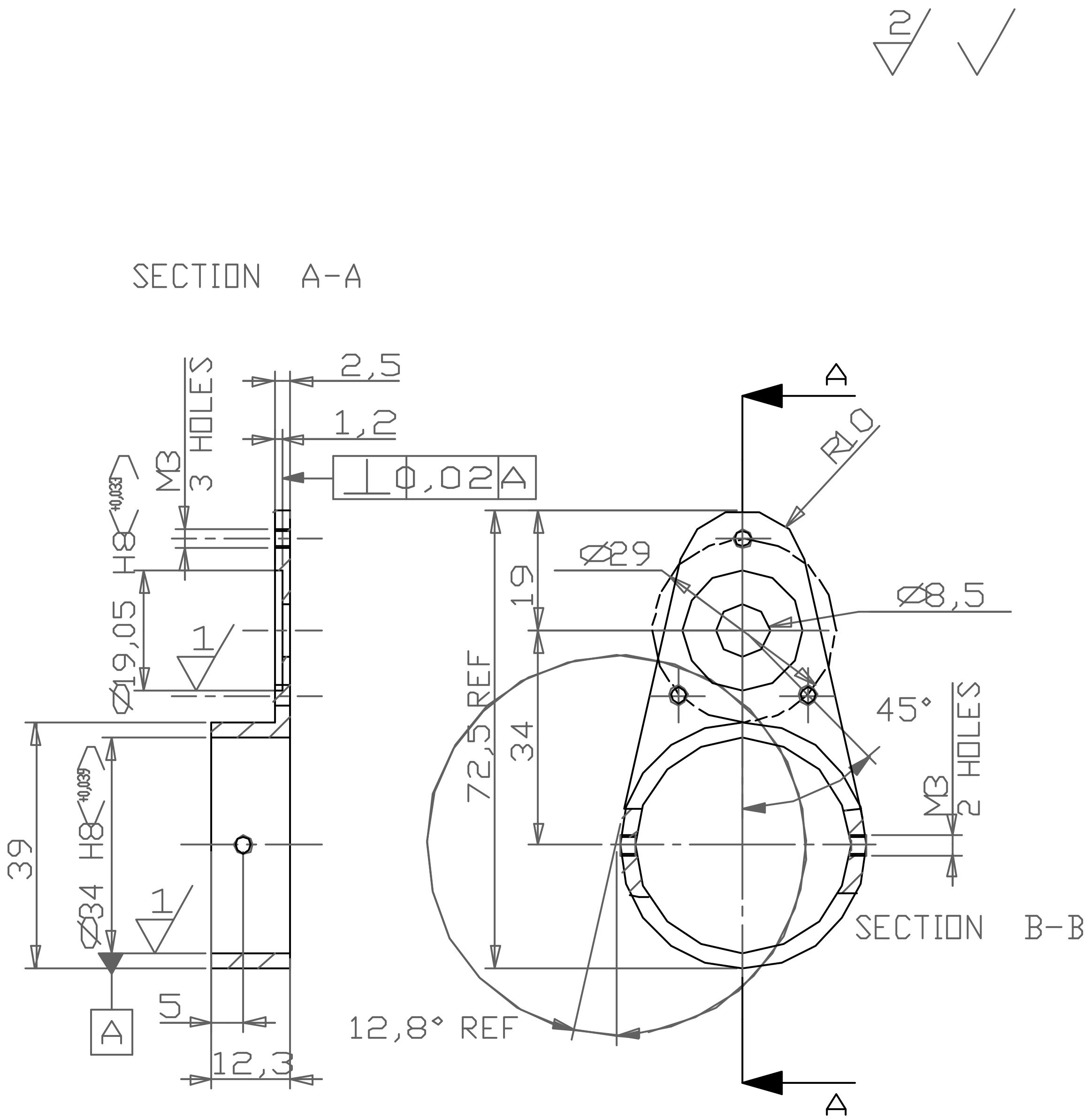

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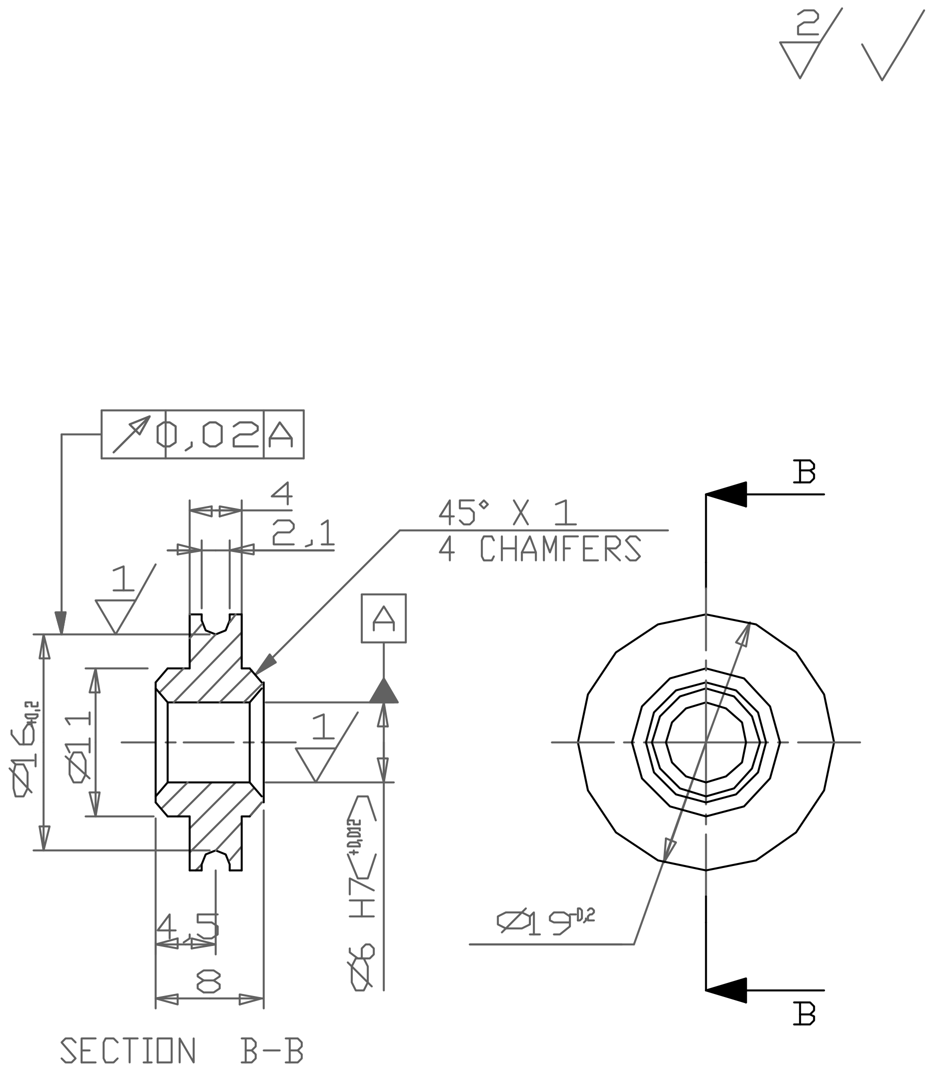
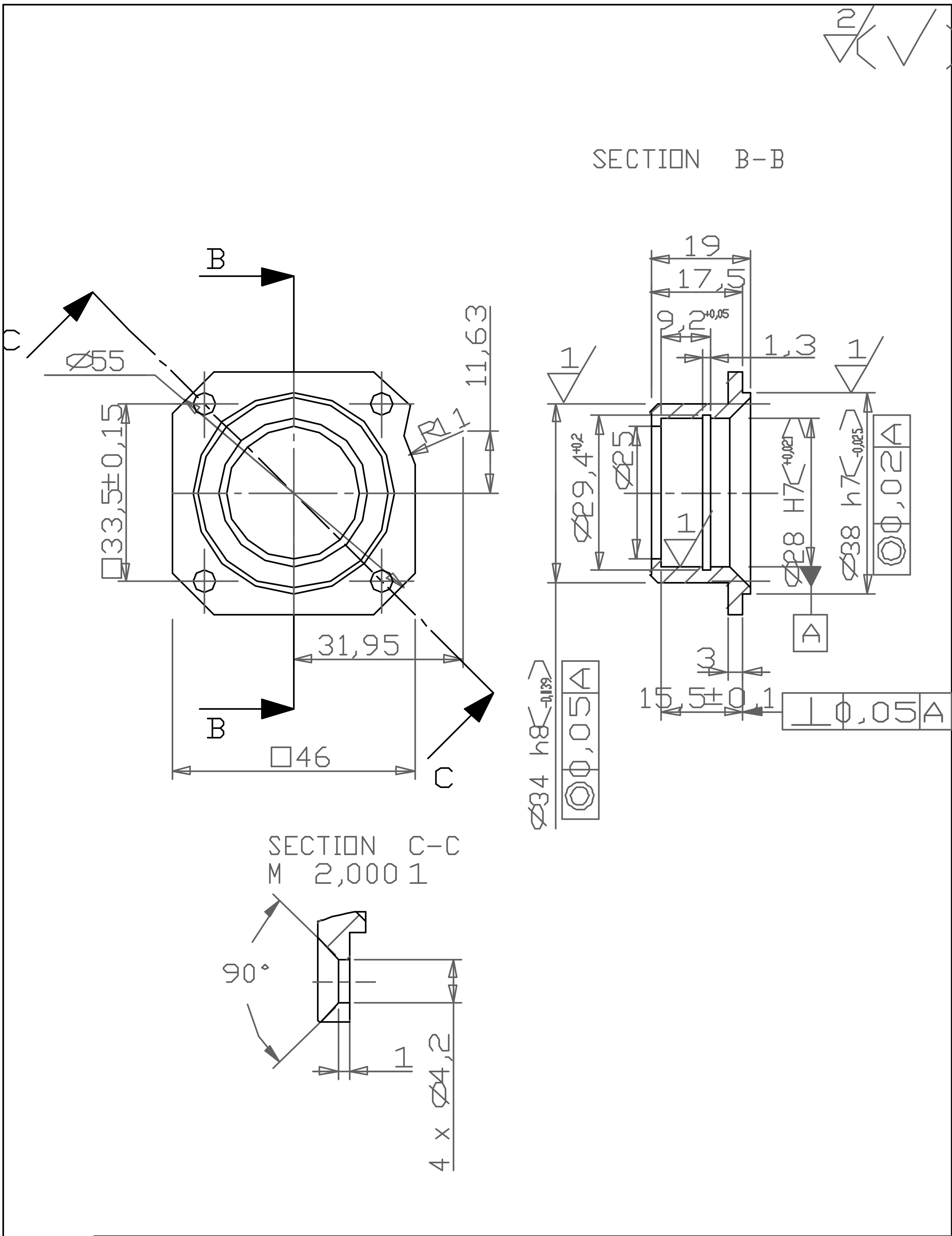
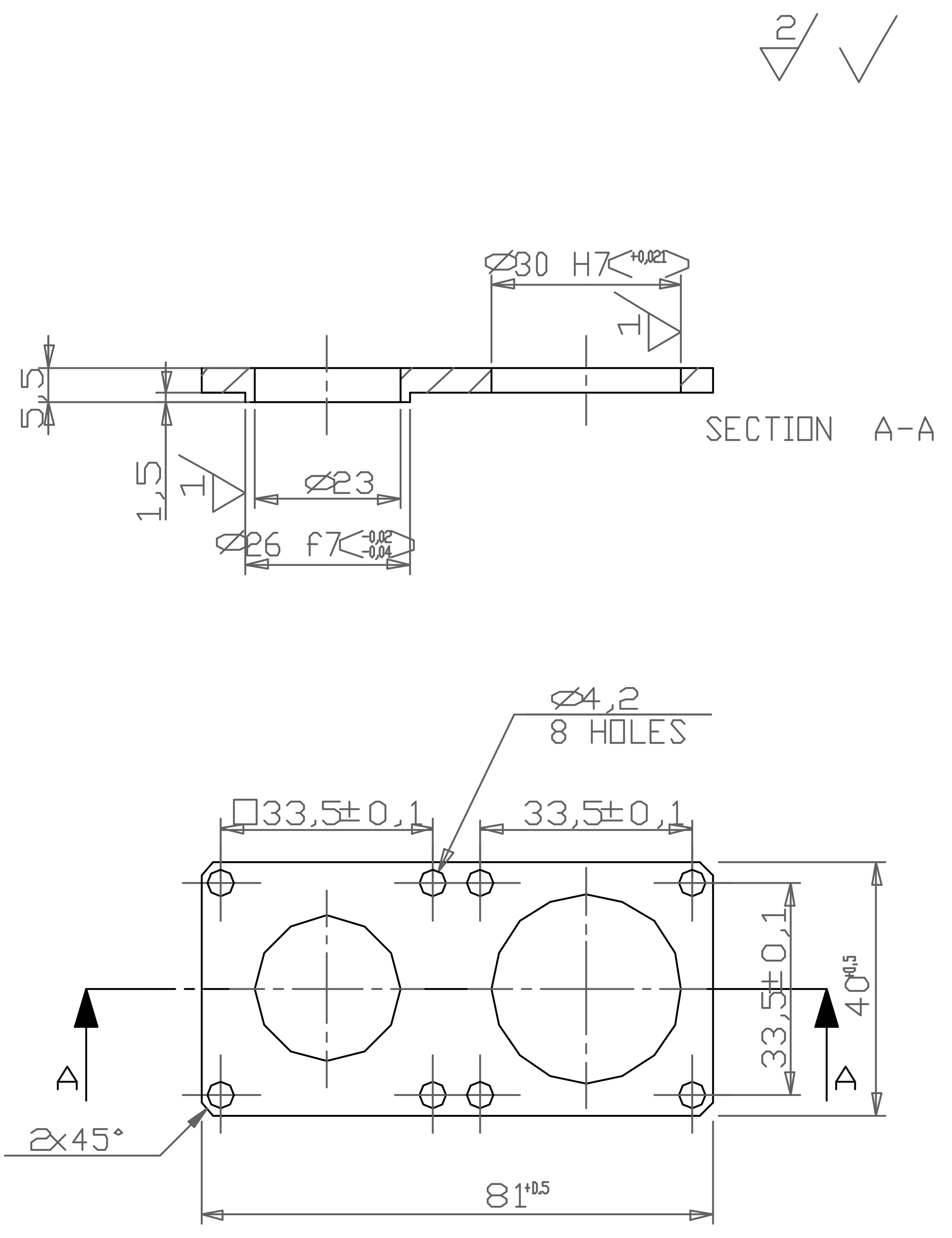


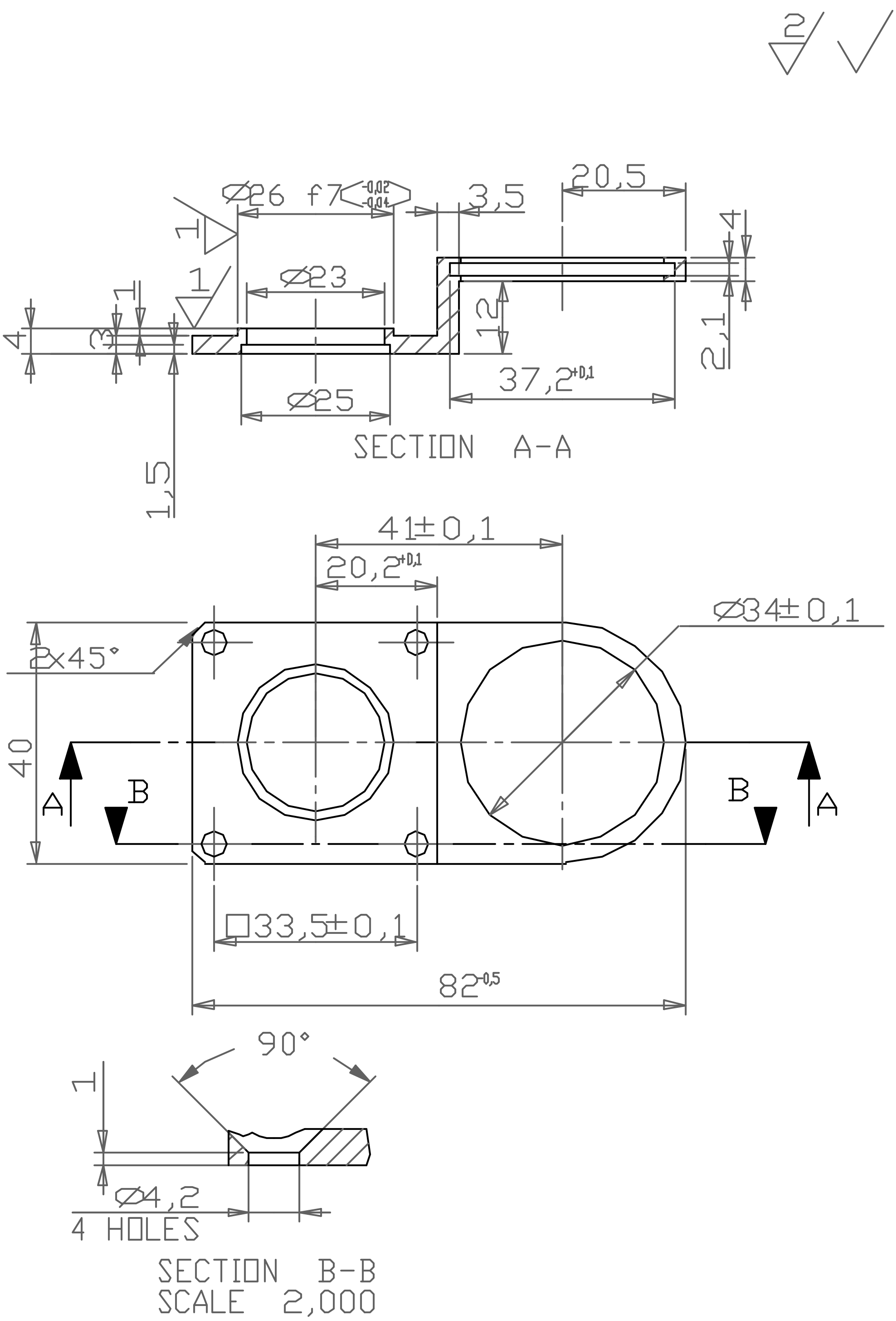
		PM.01.04.00.23	
		PULLEY	Scale
			2:1
File	PM01040023	PLU	



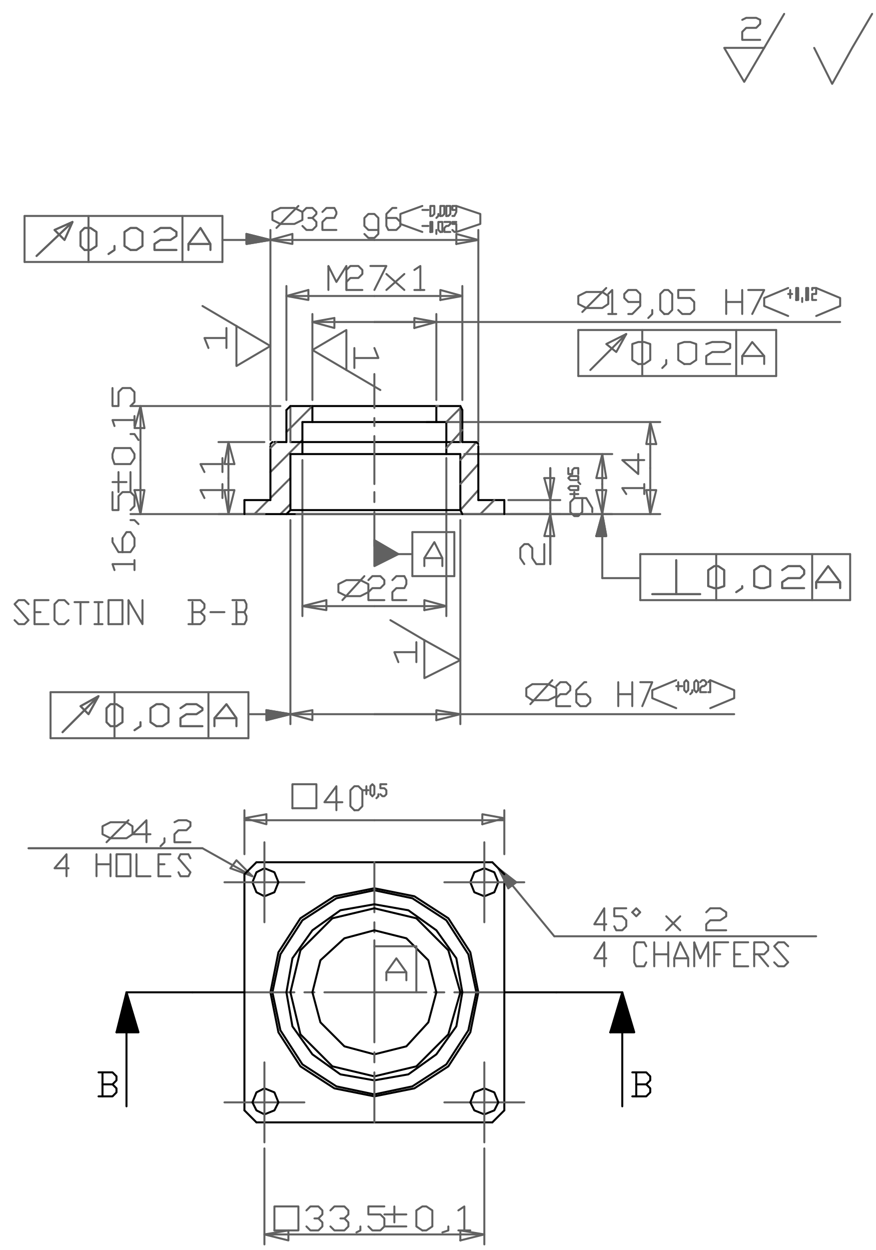
		PM.01.04.00.25	
		BEARING INSERT FOR ⌀28x8	Scale 1:1
File	040025	Al	



		PM.01.04.00.26	
		CONSOLE MOTOR	Scale
			1:1
File	PM01040026	St45	

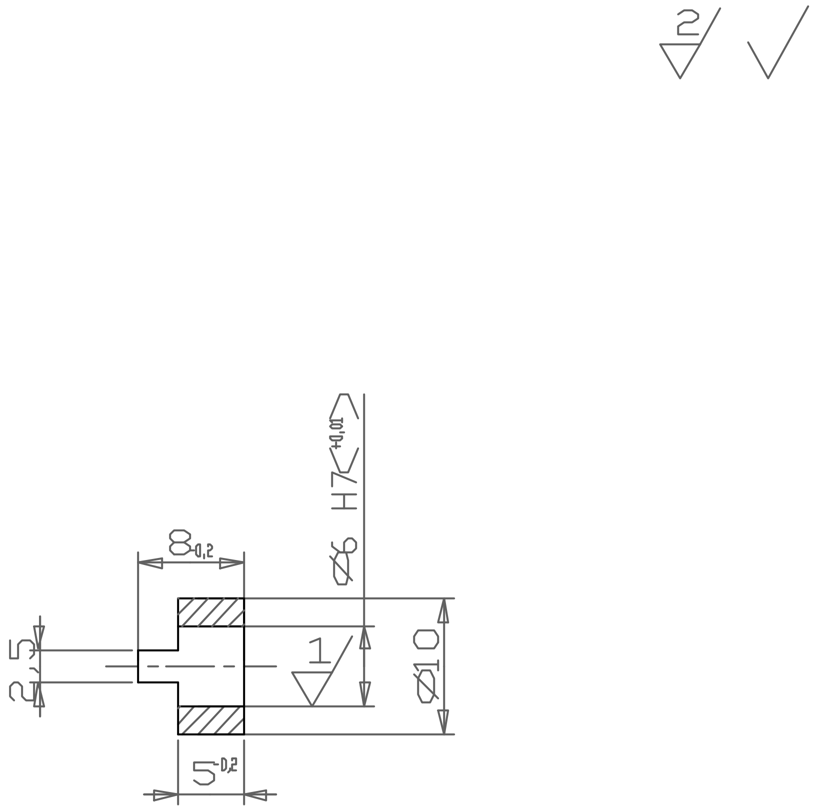


		PM.01.04.00.31	
		CONSOLE III	Scale
			1:1
File	PM01040031	St45	



* 4 holes Ø4,2 are fitted to the holes
on CROSS YOKE- PM.01.04.00.12

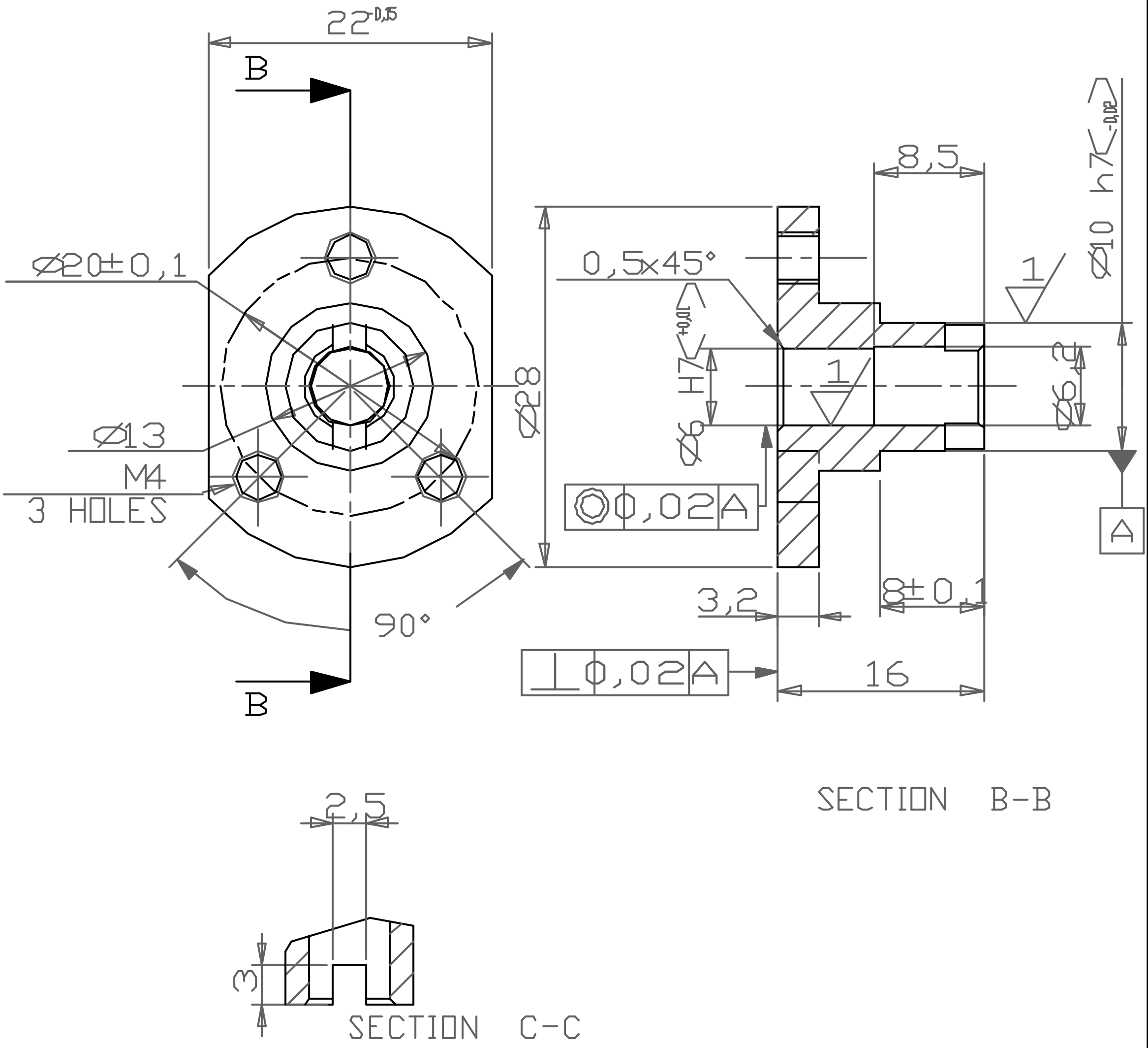
		PM.01.04.00.32	
		BEARING INSERT	Scale
			1:1
File	PM01040032	Al	



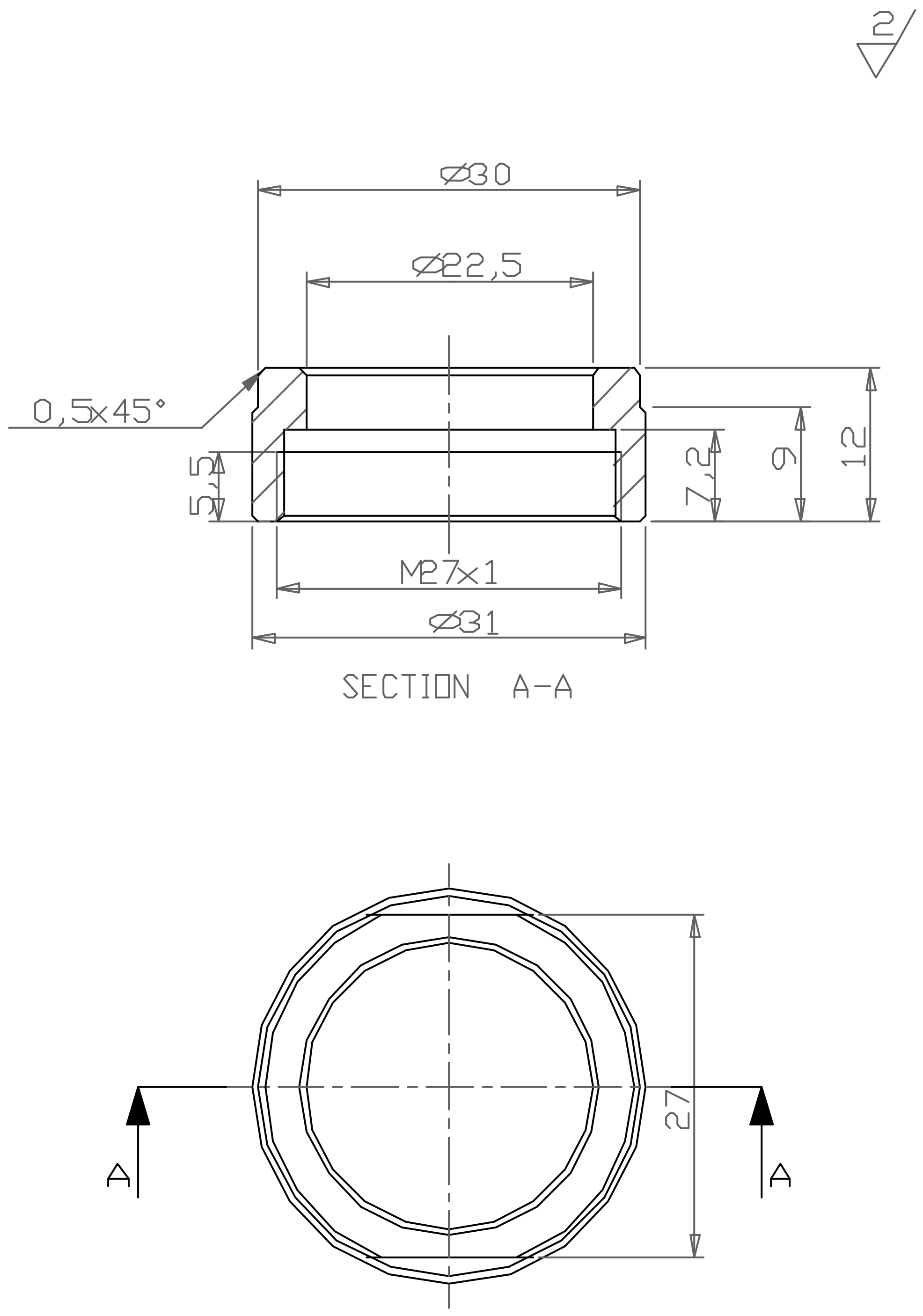
SECTION A-A

Tooth 2,5 mm is fitted to PM.01.04.00.34 with mandrel Ø6 and tollerance 0.02 mm

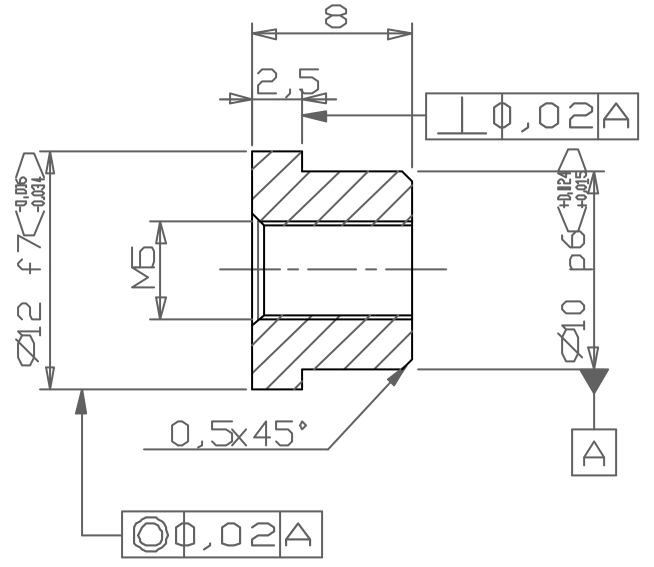
		PM.01.04.00.33	
		TOOTHED BUSHING	Scale 2:1
File	040033	Al	



		PM.01.04.00.34	
		BUSHING II	Scale
			2:1
File	PM01040034	St45	



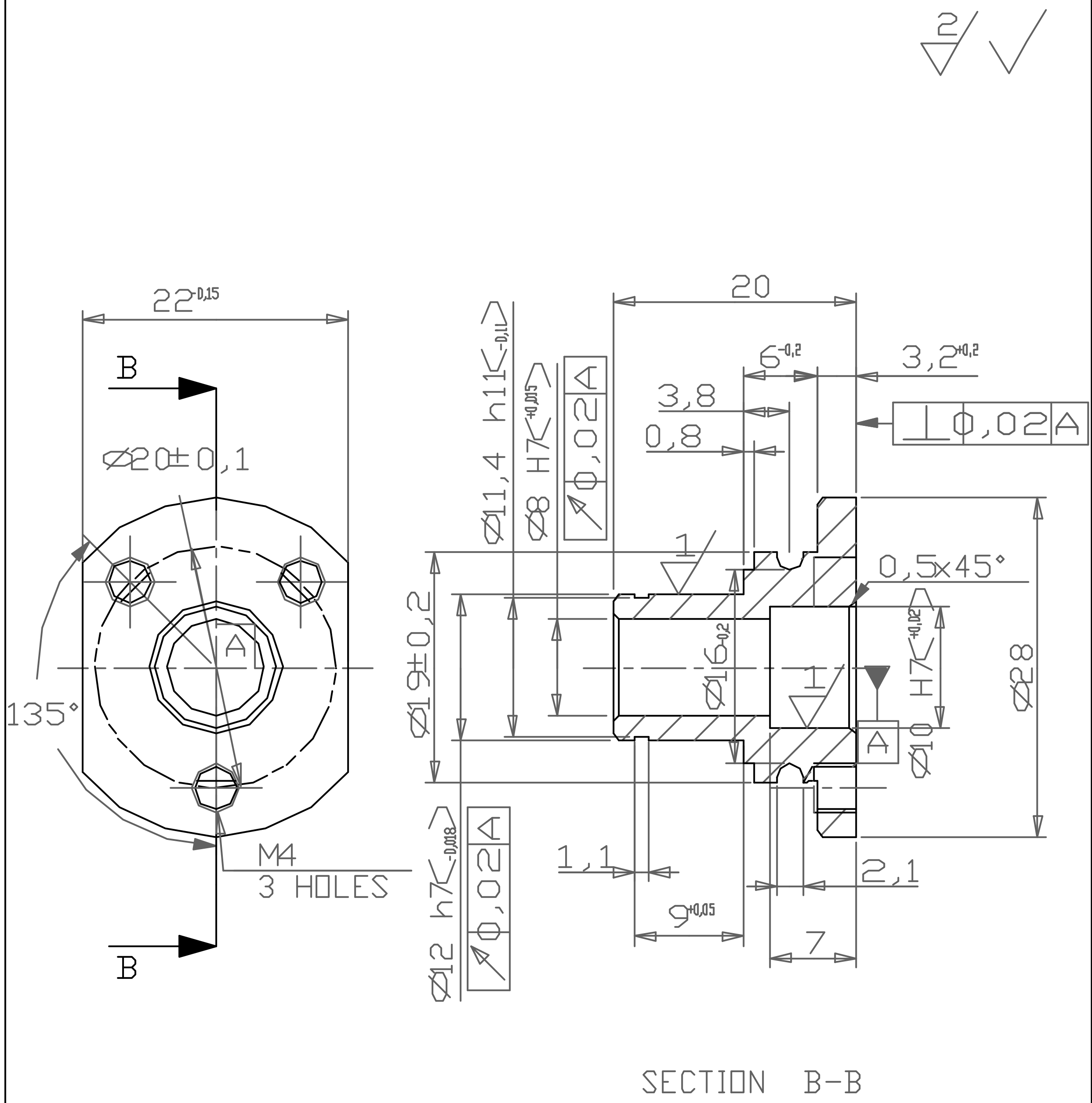
		PM.01.04.00.36	
		NUT SPECIAL	Scale
			2:1
File	PM01040036	Al	



SECTION B-B

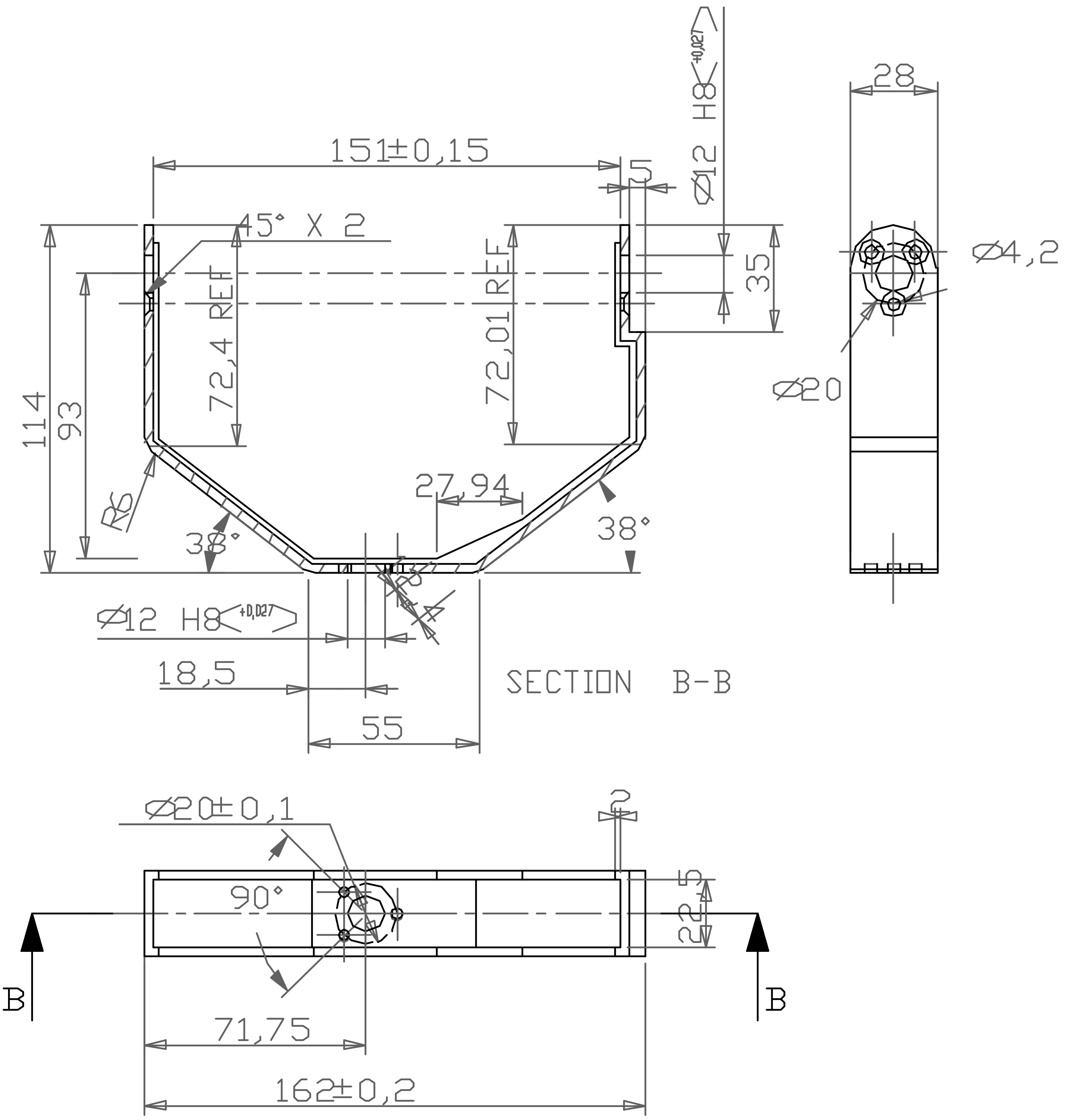
Generic Part Name: PM.01.04.00.37	
	d0
ORIGINAL	Ø10,000 p6
PM01040038	Ø6,000 p6

		PM.01.04.00.37	
		CENTER BUSHING	Scale
			2:1
File	PM01040037	Al	

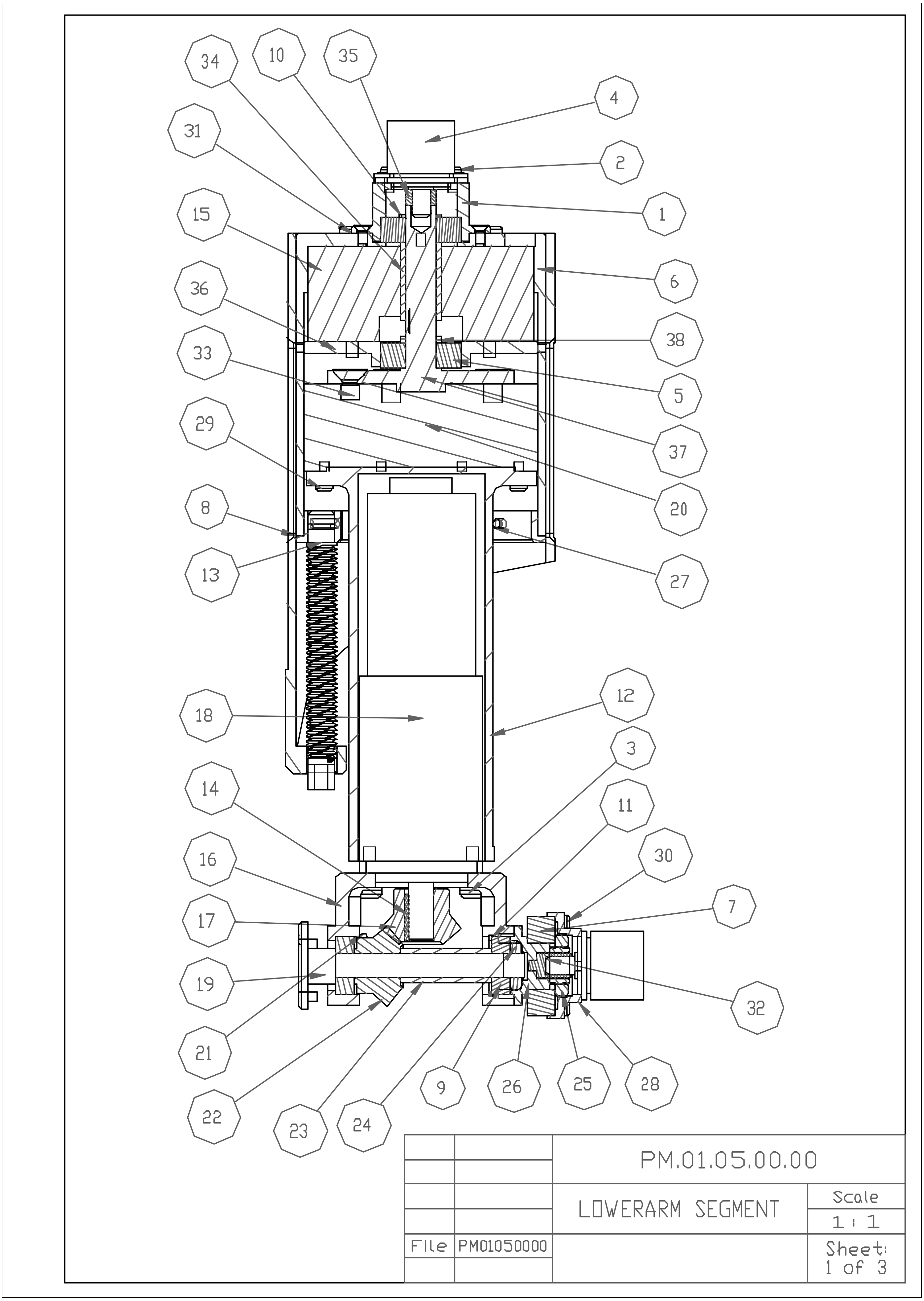


* 3 holes M4 are fitted to the holes in
FORK 1 - PM.01.04.01.00

		PM.01.04.00.39	
		PULLEY BUSHING	Scale
			2:1
File	PM01040039	Al	



		PM.01.04.02.00	
		FORK 2	Scale 1:2
File	0402	St45	


34
10
35
4
31
2
1
15
6
36
38
33
5
29
37
20
8
27
13
12
18
3
14
11
30
16
7
17
19
32
21
26
25
28
9
22
23
24
PM.01.05.00.00
LOWERARM SEGMENT
Scale
1 : 1
File
PM01050000
Sheet:
1 of 3

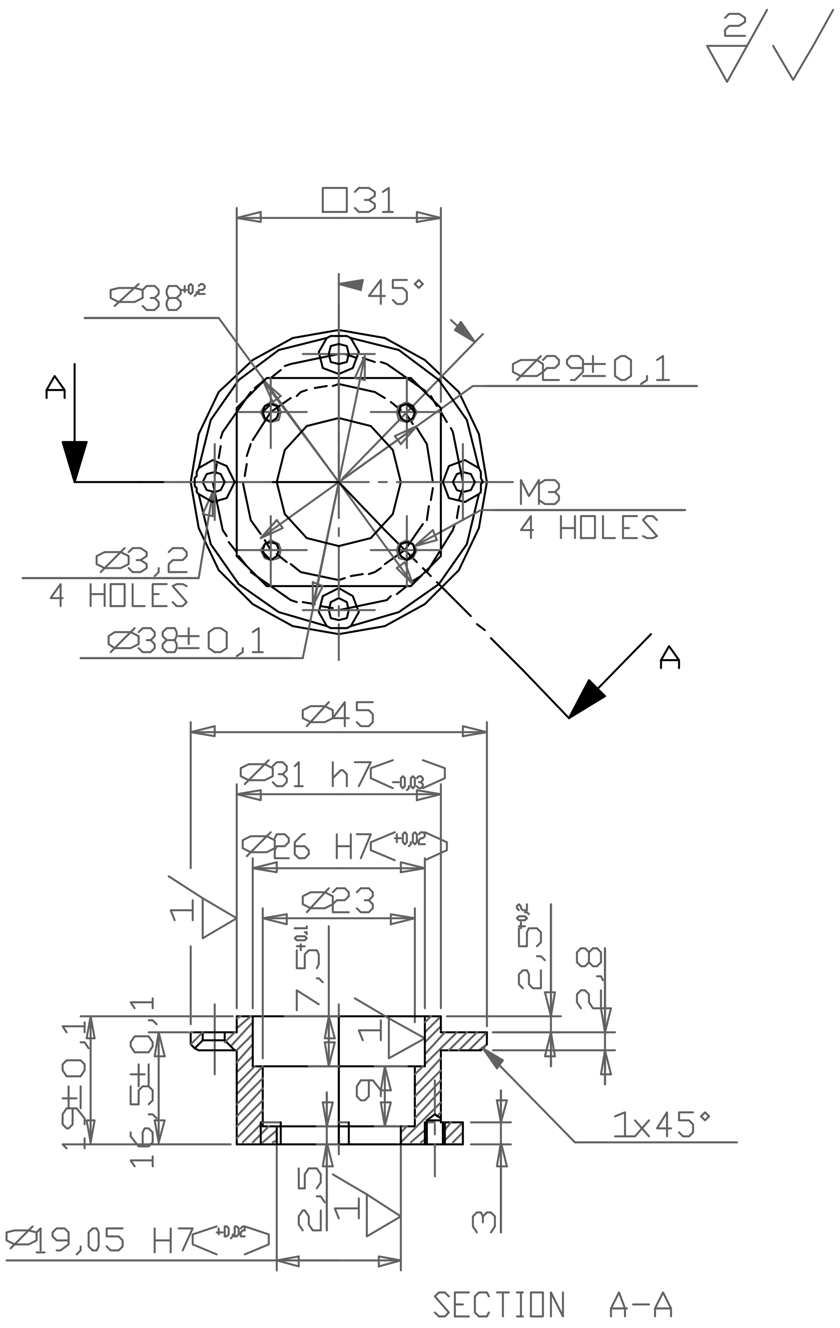
SECTION A-A

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
1	PM.01.05.00.01	A.S. CONSOLE	PART	1
2		A.S. SCREW	ASSEMBLY	6
		A.S. BRACKET	PART	1
		Screw M3 x 5 (ISO)	PART	1
		Washer M3	PART	1
3		SCREW M4x12 & WASHER	ASSEMBLY	4
		Screw ISO-M4 x 12	PART	1
		WASHER ISO M4	PART	1
4		ANGULAR SENSOR	PART	2
5		BEARING Ø10xØ26x8	PART	2
6	PM.01.05.01.00	INSIDE BUSHING	ASSEMBLY	1
	PM.01.05.01.01	BUSHING	PART	1
	PM.01.05.01.02	RING	PART	1
		SCREW ISO M3x6	PART	2
		SCREW ISO M3x12	PART	2
7		BEARING D15xD32x9	PART	1
8	PM.01.05.00.08	OUTER BUSHING	PART	1
9		BEARING D8xD19x6	PART	2
10		CIRCLIP d10	PART	1
11		CIRCLIP D19	PART	1
12	PM.01.05.00.12	MOTOR CASING	PART	1
13	PM.01.05.00.13	ADJUSTING SCREW	PART	1
14	PM.01.04.00.06	COTTER 1.8x3x15	PART	1
15		DC BRAKE	PART	1
16	PM.01.05.00.16	LOWERARM FORK	PART	1

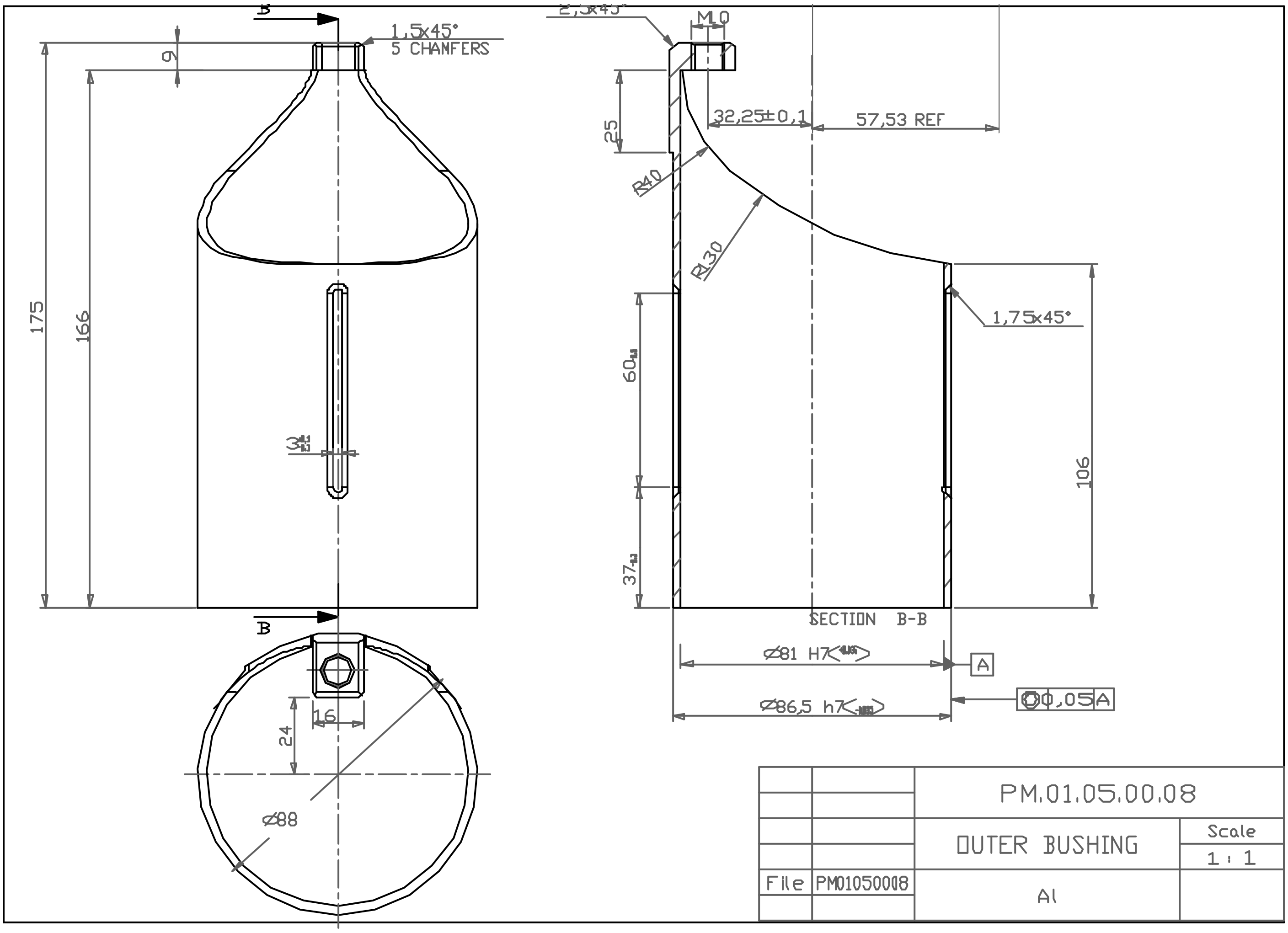
		PM.01.05.00.00	
		LOWERARM SEGMENT	Scale 1:1
File	PM01050000		Sheet: 2 of 3

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
17	PM.01.05.00.17	CONICAL GEAR	PART	1
18		DC MOTOR/GEAR	PART	1
19	PM.01.05.00.19	BEARING AXLE	PART	1
20		F/T SENSOR	PART	1
21	PM.01.05.00.21	COTTER 3x2,5x15	PART	1
22	PM.01.05.00.22	CONICAL GEAR II	PART	1
23	PM.01.05.00.23	SPACER	PART	1
24		HEX. NUT M8x1 H=3.5	PART	1
25		NUT M12x0.5 H=4	PART	1
26	PM.01.05.00.26	BEARING CAP	PART	1
27		SCREW ISO M3x6	PART	11
28	PM.01.05.00.28	A.S. CAP	PART	1
29		SCREW ISO M3x8	PART	8
30		SCREW ISO M3x12	PART	4
31		SCREW ISO M4x40	PART	4
32	PM.01.05.00.32	TOOTHED BUSH	PART	1
33		SCREW ISO M6x10	PART	4
34	PM.01.05.00.40	SPACER 1	PART	1
35	PM.01.05.00.42	TOOTHED BUSHING	PART	1
36	PM.01.05.00.36	BEARING CAP	PART	1
37	PM.01.05.00.37	F/T AXLE	PART	1
38	PM.01.05.00.38	SPACER 2	PART	1

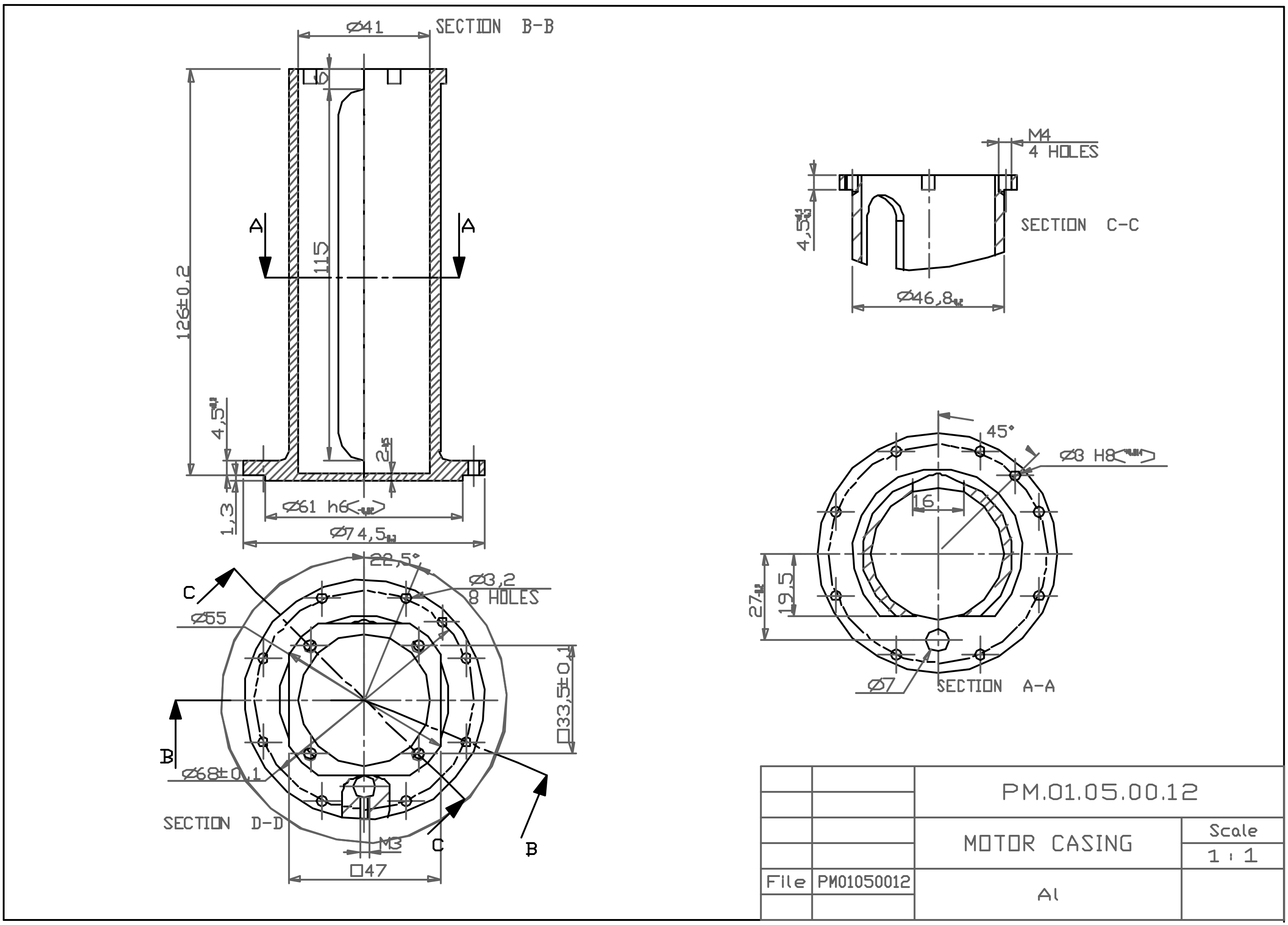
		PM.01.05.00.00	
		LOWERARM SEGMENT	Scale 1:1
File	PM01050000		Sheet: 3 of 3



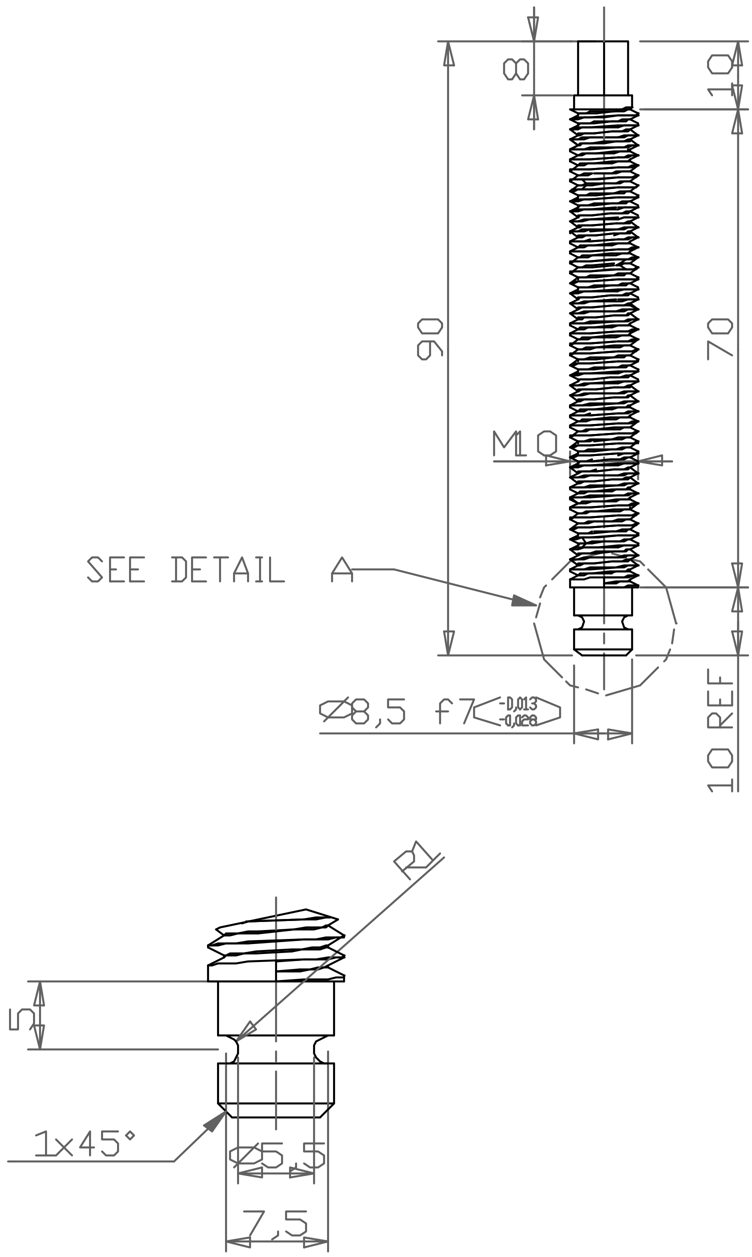
		PM.01.05.00.01	
		A.S. CONSOLE	Scale
			1:1
File	PM01050001	Al	



1,5x45°
5 CHAMFERS
2,5x45°
M10
32,25±0,1
57,53 REF
R40
R30
1,75x45°
175
166
9
25
60
37
106
SECTION B-B
Ø81 H7
Ø86,5 h7
A
0,05 A
16
24
Ø88
B
PM.01.05.00.08
OUTER BUSHING
Scale
1 : 1
File PM01050008
Al

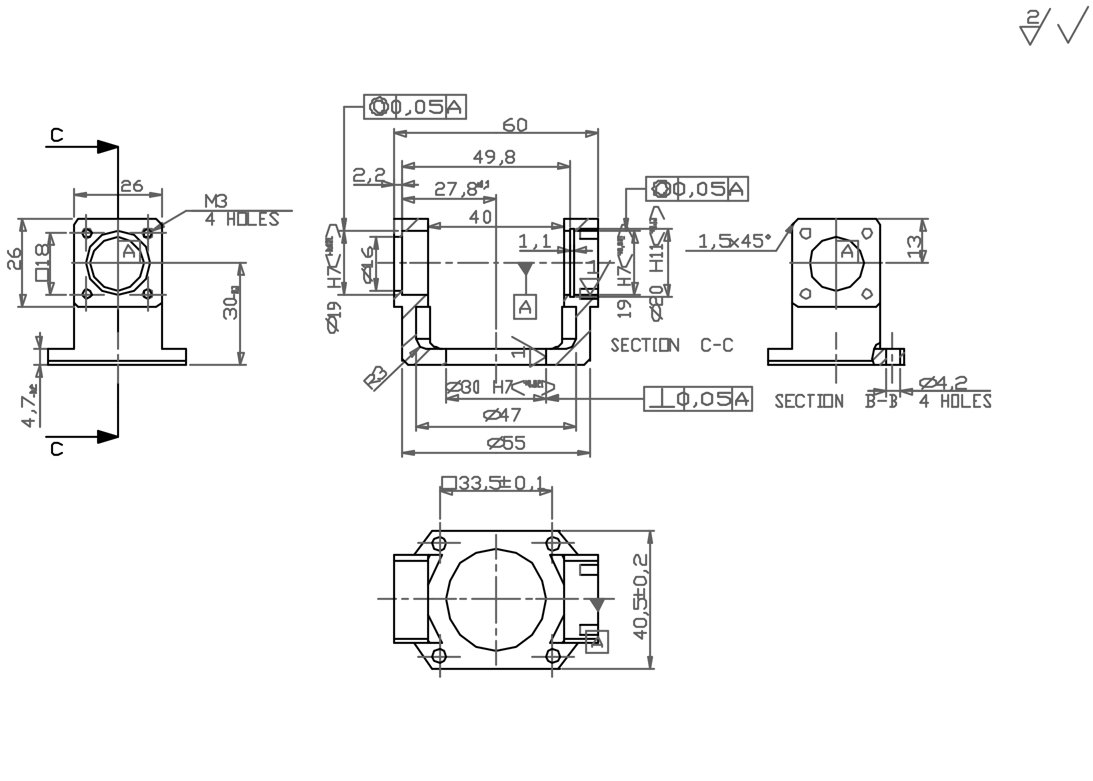


Ø41
SECTION B-B
115
126±0,2
4,5
2,5
1,3
Ø61 h6
Ø74,5
M4
4 HOLES
SECTION C-C
Ø46,8
22,5°
Ø3,2
8 HOLES
Ø55
□33,5±0,1
Ø68±0,1
SECTION D-D
M3
□47
45°
Ø3 H8
16
27
19,5
Ø7
SECTION A-A
PM.01.05.00.12
MOTOR CASING
Scale
1 : 1
File PM01050012
Al

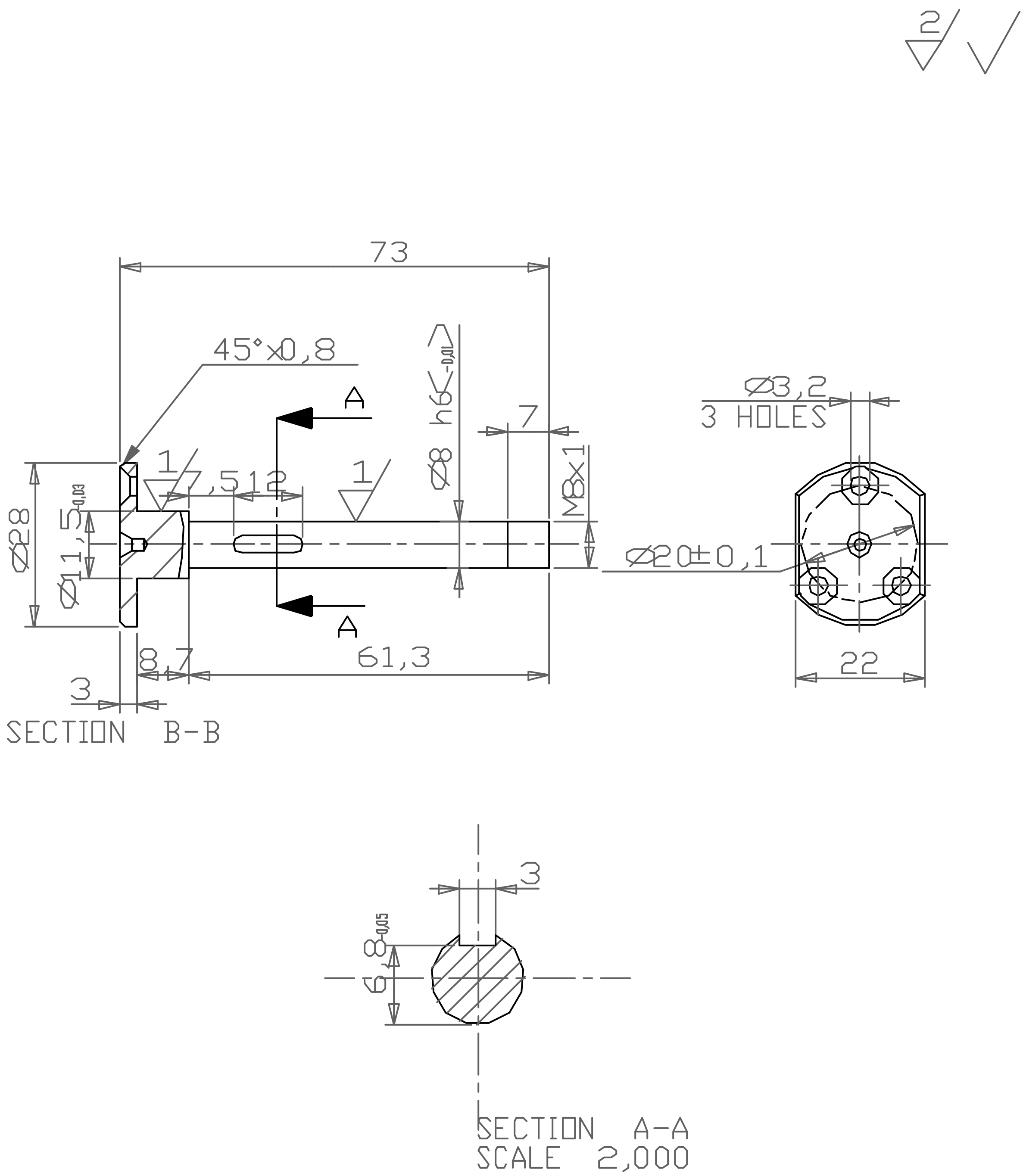


DETAIL A
SCALE 2,000

		PM.01.05.00.13	
		ADJUSTING SCREW	Scale
			1:1
File	PM01050013	St45	

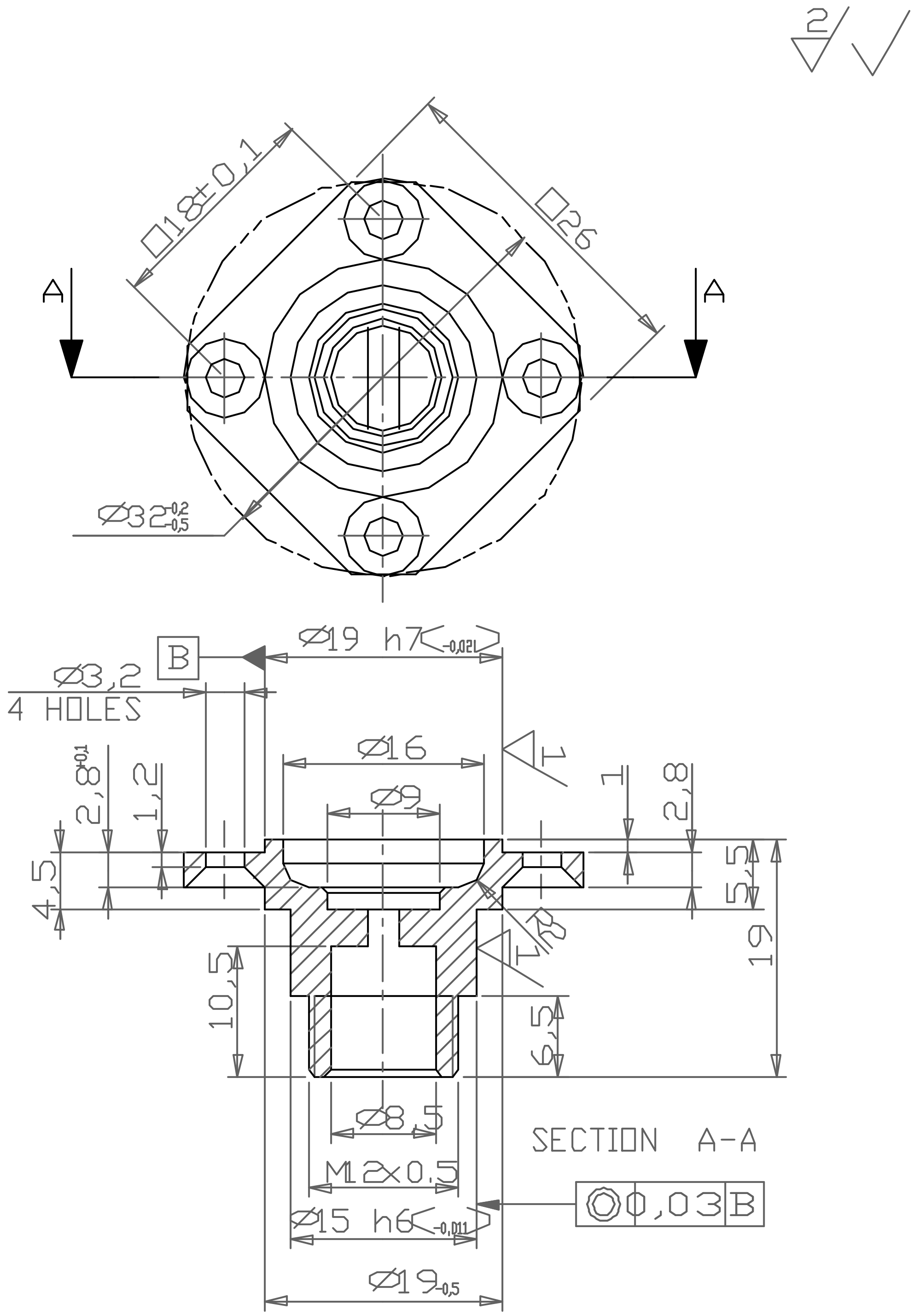


		PM.01.05.00.16	
		LOWERARM FORK	Scale 1 : 1
File	PM01050016	Al	

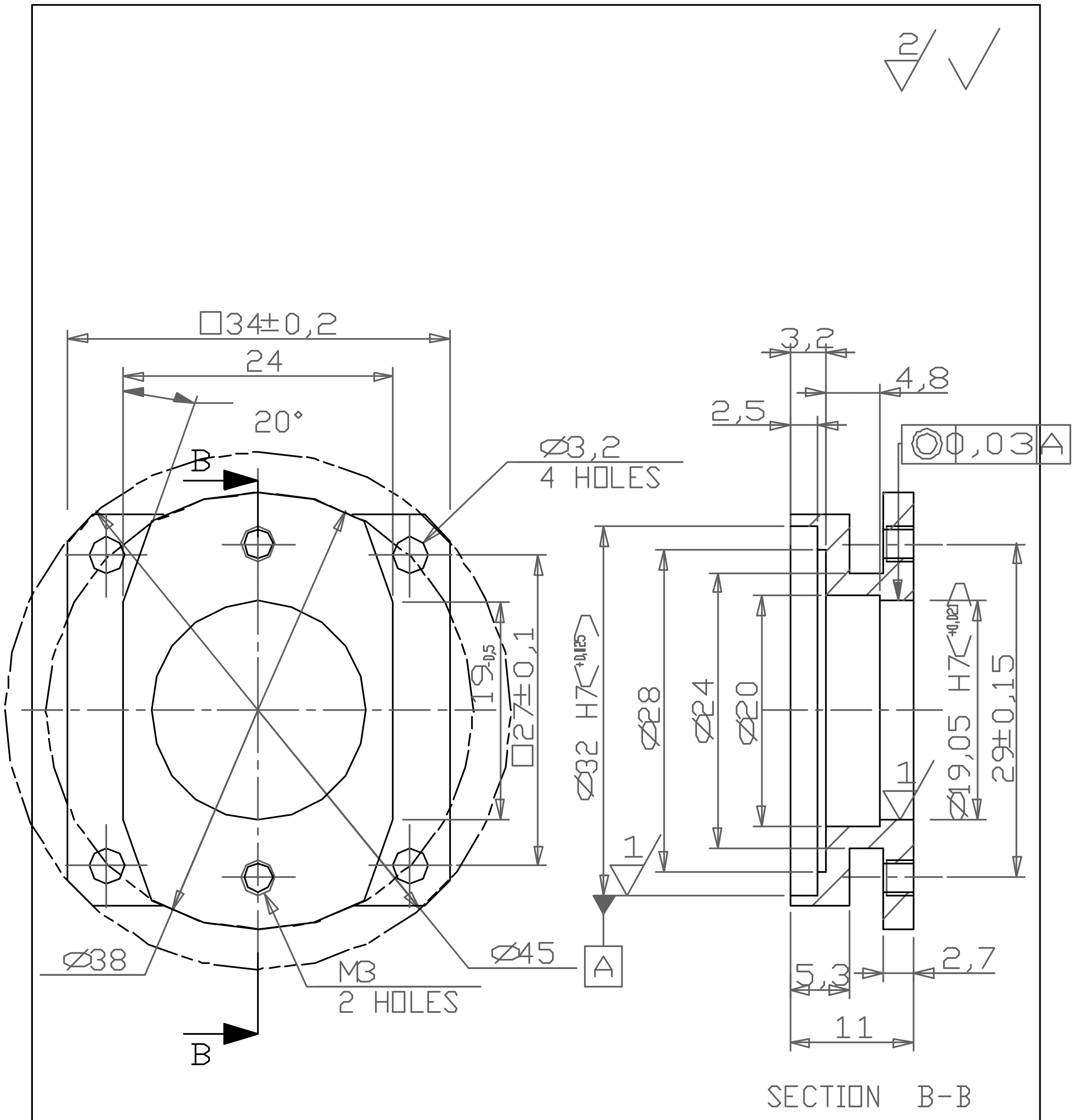


* Heat treatement - HRC - 38 ...42
* Dim Ø8h6 and Ø11.5 to be grinded after heat treatment

		PM.01.05.00.19	
		BEARING AXLE	Scale
			1: 1
File	PM01050019	St40X	

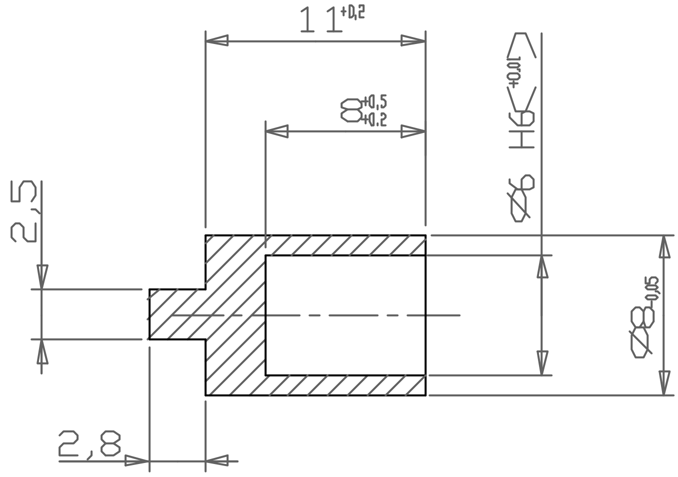


		PM.01.05.00.26
		BEARING CAP
		Scale 2:1
File	PM01050026	St45



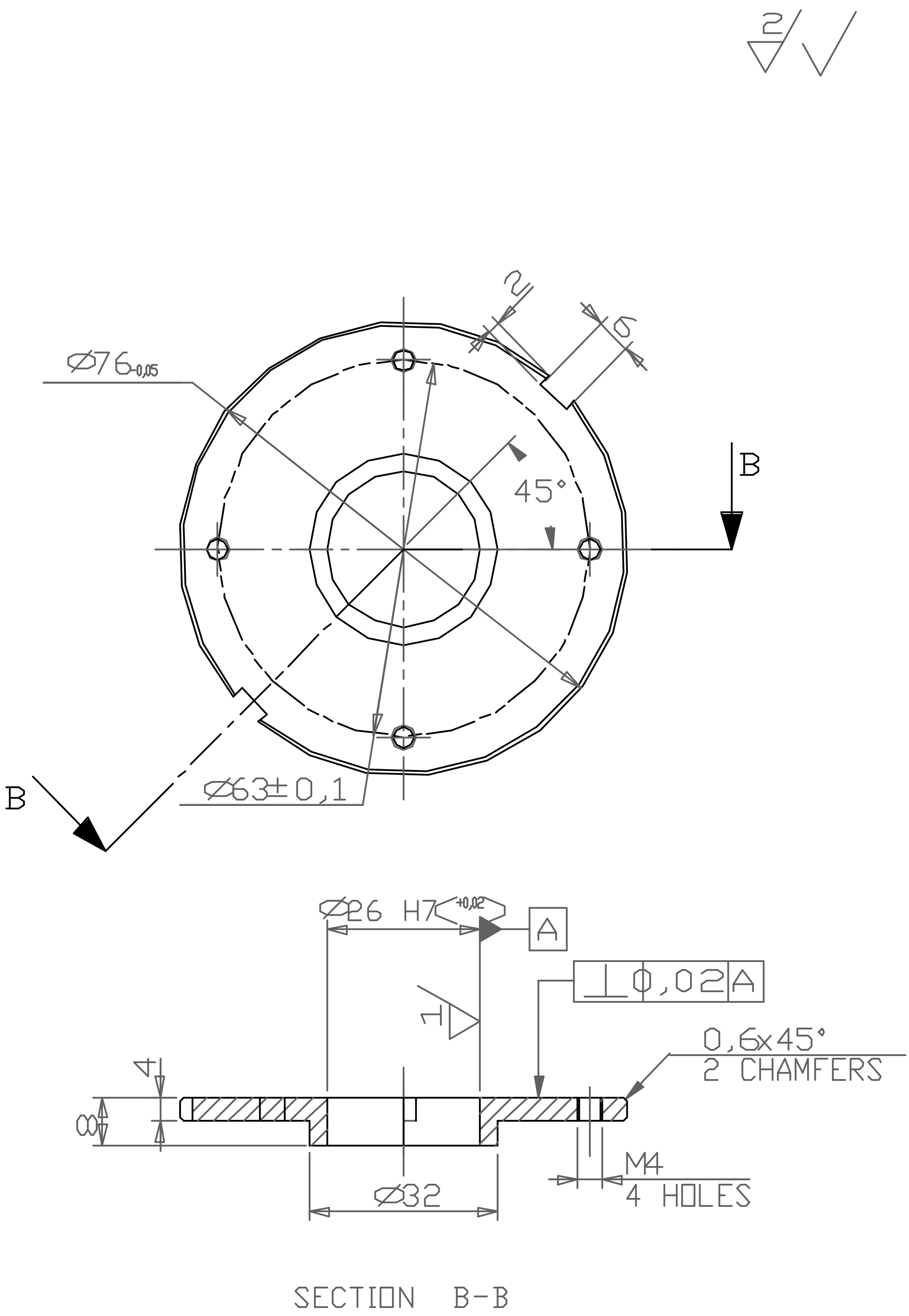
4 Holes Ø3,2 are fitted to PM.01.06.00.01

		PM.01.05.00.28	
		A.S. CAP	Scale
			2:1
File	PM01050028	Al	

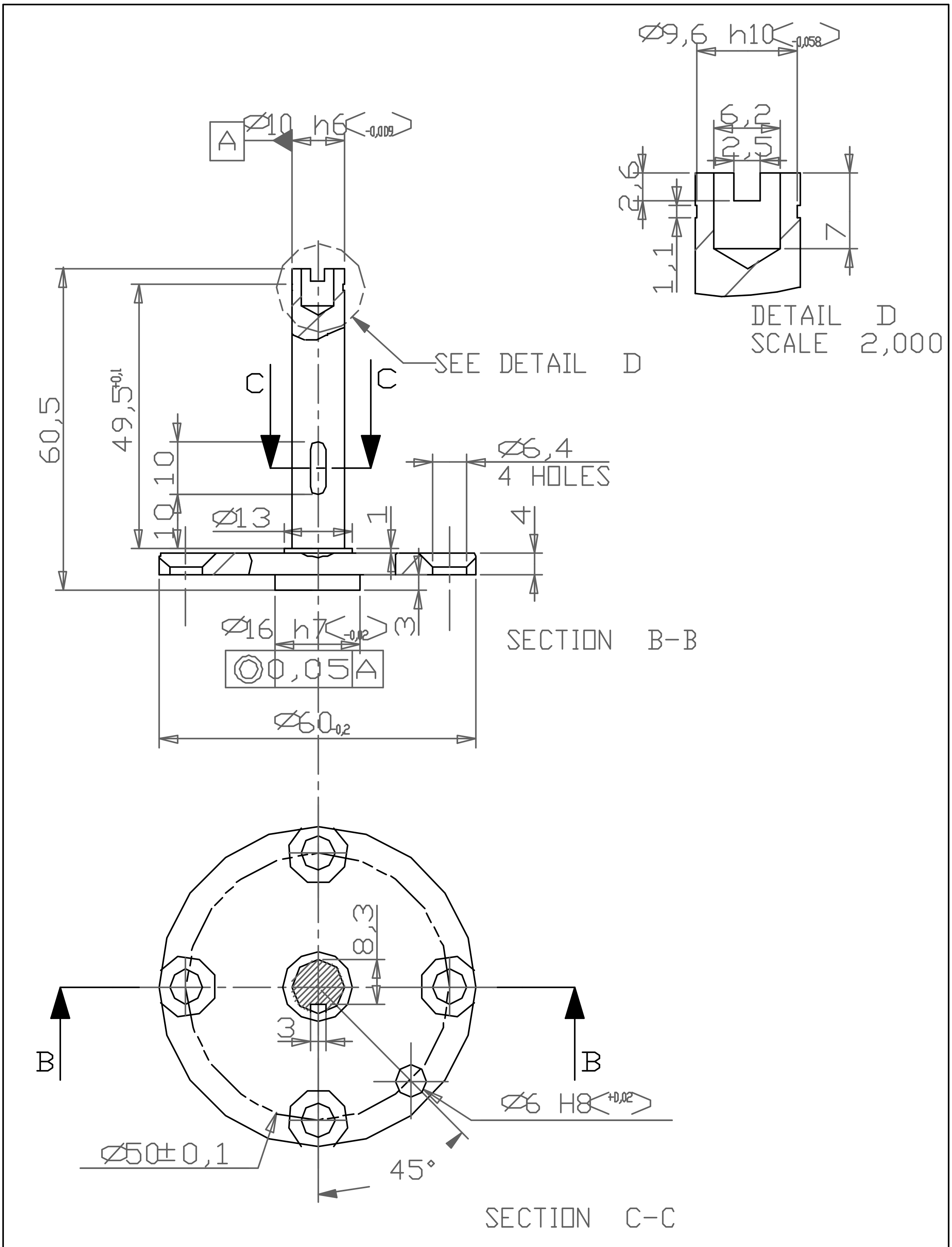


SECTION A-A

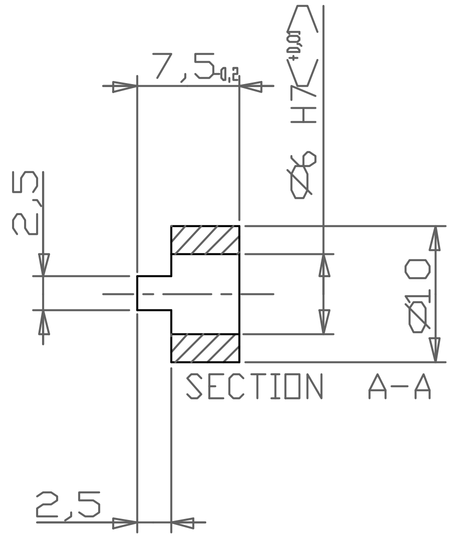
		PM.01.05.00.32	
		TOOTHED BUSH	Scale
			3 1
File	PM01050032	Al	



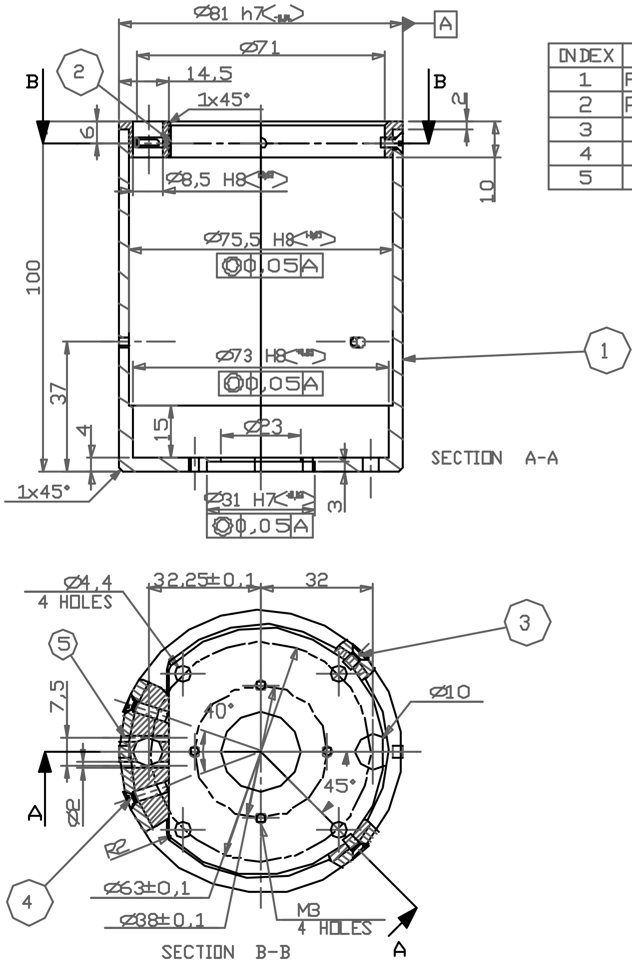
		PM.01.05.00.36		
		BEARING CAP		Scale
				1:1
File	PM01050036	Al		



		PM.01.05.00.37	
		F/T AXLE	Scale 1:1
File	PM01050037	St45	

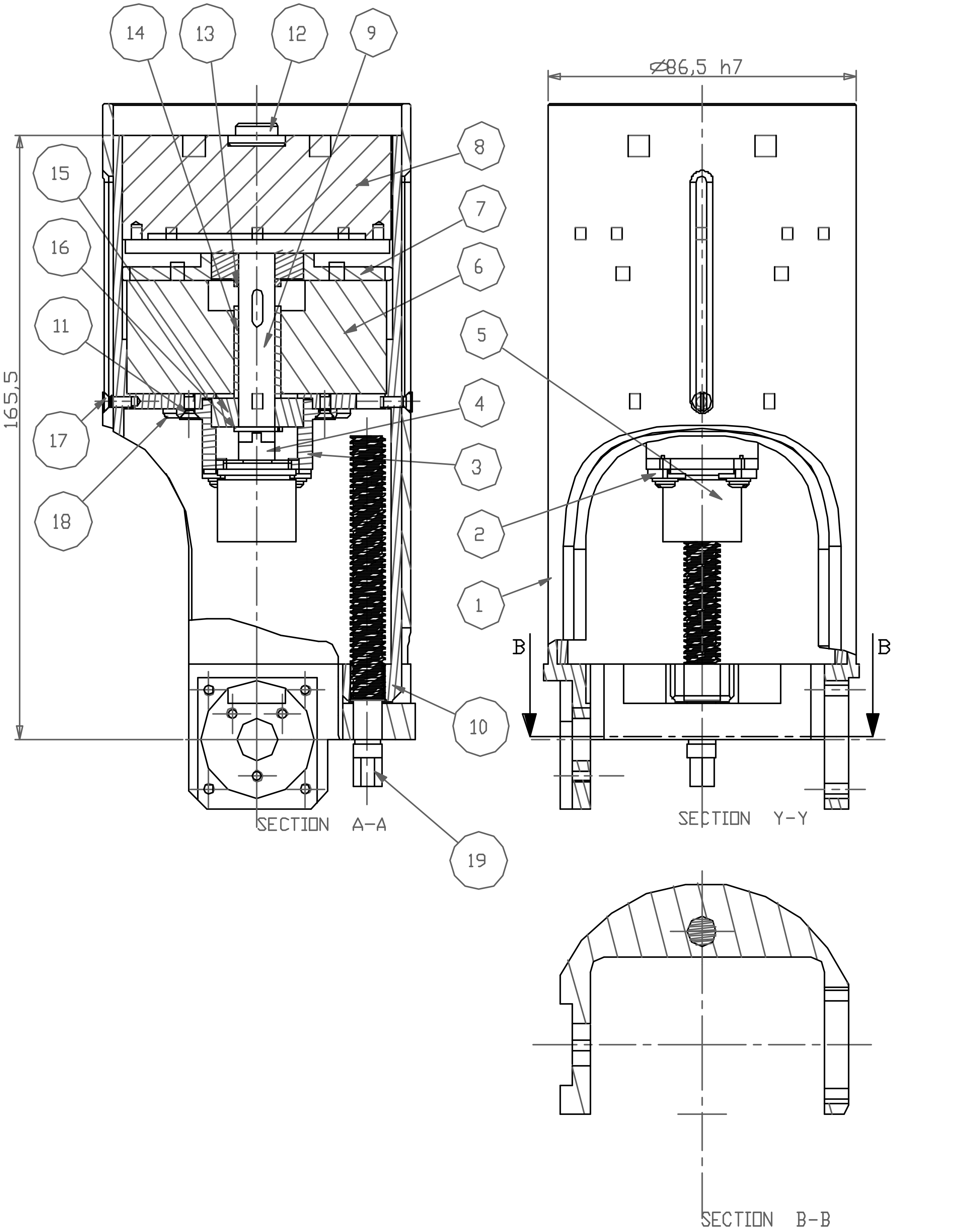


		PM.01.05.00.42	
		TOOTHED BUSHING	Scale
			2:1
File	PM01050042	Al	



INDEX	Component Name	Comp. Type	Qty.	Info
1	PM.01.05.01.01	PART	1	BUSHING
2	PM.01.05.01.02	PART	1	RING
3		PART	2	SCREW ISO M3x6
4		PART	2	SCREW ISO M3x12
5		PART	2	PIN Ø2x14

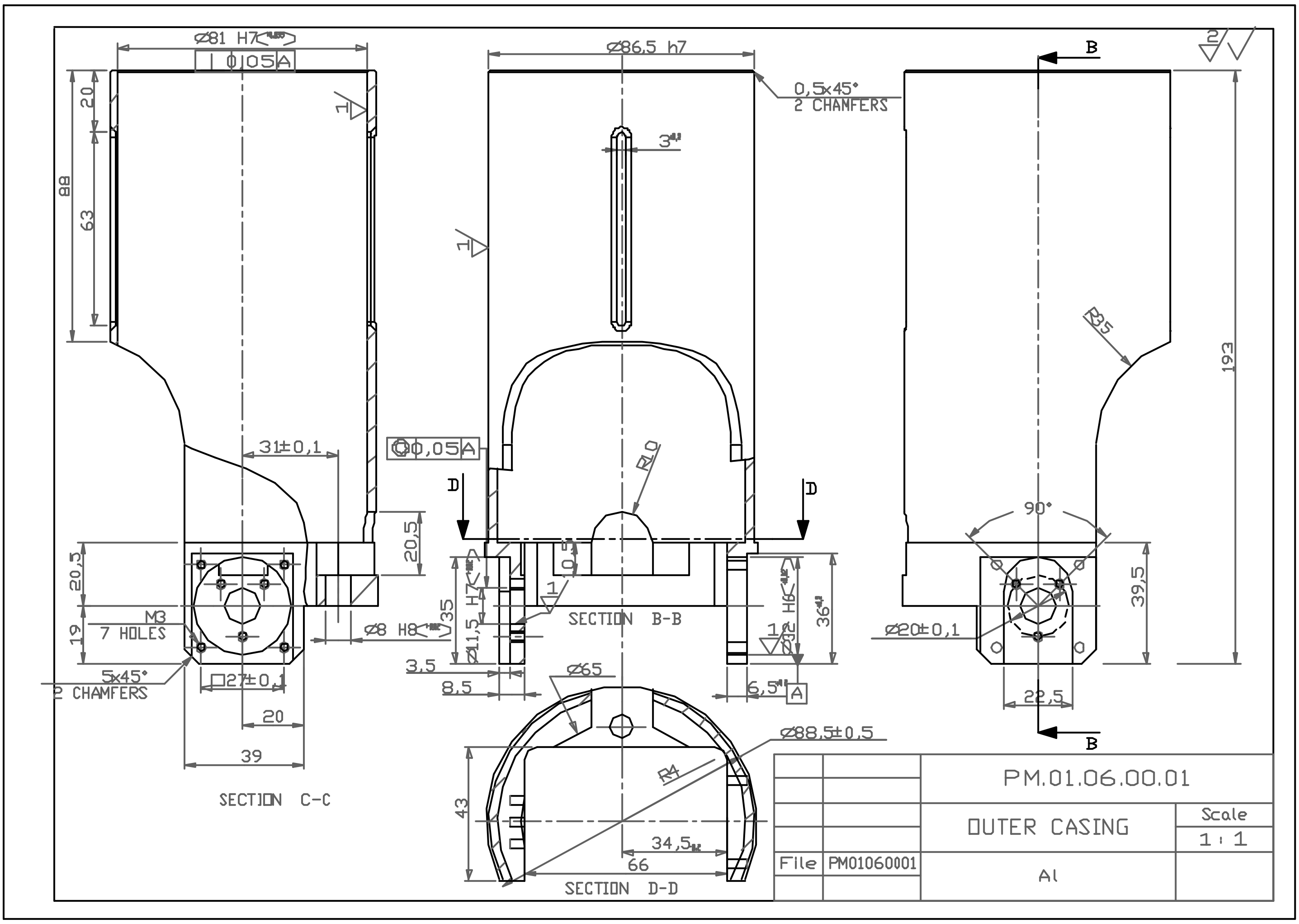
		PM.01.05.01.00	
		INSIDE BUSHING	Scale 1 : 1
File	PM01050100		



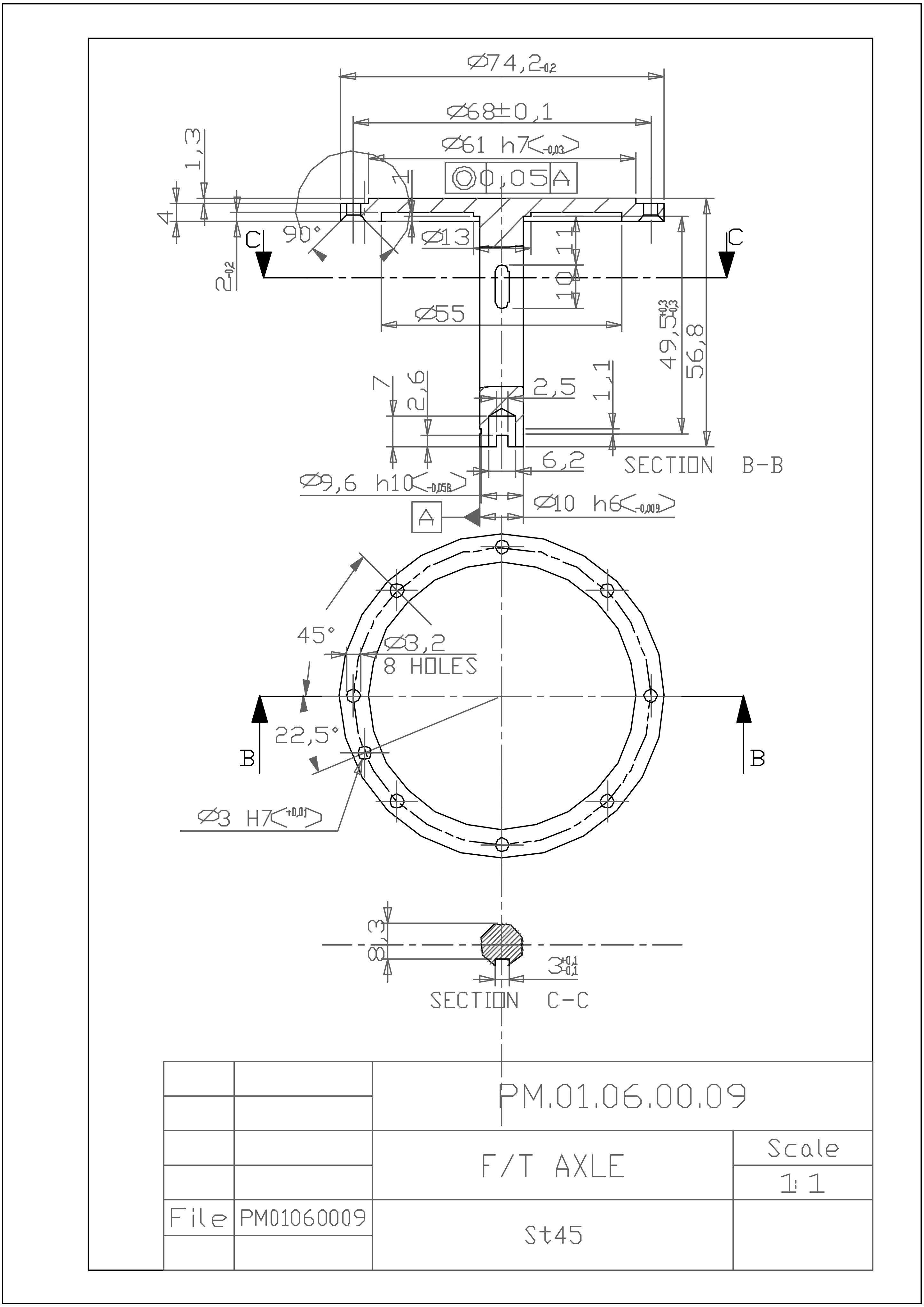
		PM.01.06.00.00	
		UPPERARM	Scale 1 : 1
File	PM01060000		Sheet: 1 of 2

INDEX	ITEM NAME	SUB-ITEM NAME	ITEM TYPE	QTY
1	PM.01.06.00.01	OUTER CASING	PART	1
2		A.S. SCREW	ASSEMBLY	4
		A.S. BRACKET	PART	1
		Screw M3 x 5 (ISO)	PART	1
		Washer M3	PART	1
3	PM.01.05.00.01	A.S. CONSOLE	PART	1
4	PM.01.05.00.42	TOOTHED BUSHING	PART	1
5		ANGULAR SENSOR	PART	1
6		DC BRAKE	PART	1
7	PM.01.05.00.36	BEARING CAP	PART	1
8		F/T SENSOR	PART	1
9	PM.01.06.00.09	F/T AXLE	PART	1
10	PM.01.06.00.10	INSIDE CASING	PART	1
11		SCREW ISO M3x6	PART	4
12	PM.01.06.00.12	CENTER PIN	PART	1
13	PM.01.05.00.38	SPACER 2	PART	1
14	PM.01.05.00.40	SPACER 1	PART	1
15		BEARING Ø10xØ26x8	PART	2
16		CIRCLIP d10	PART	1
17		Screw ISO M3x8	PART	10
18		SCREW ISO M4x40	PART	4
19	PM.01.06.00.19	ADJUSTMENT SCREW	PART	1

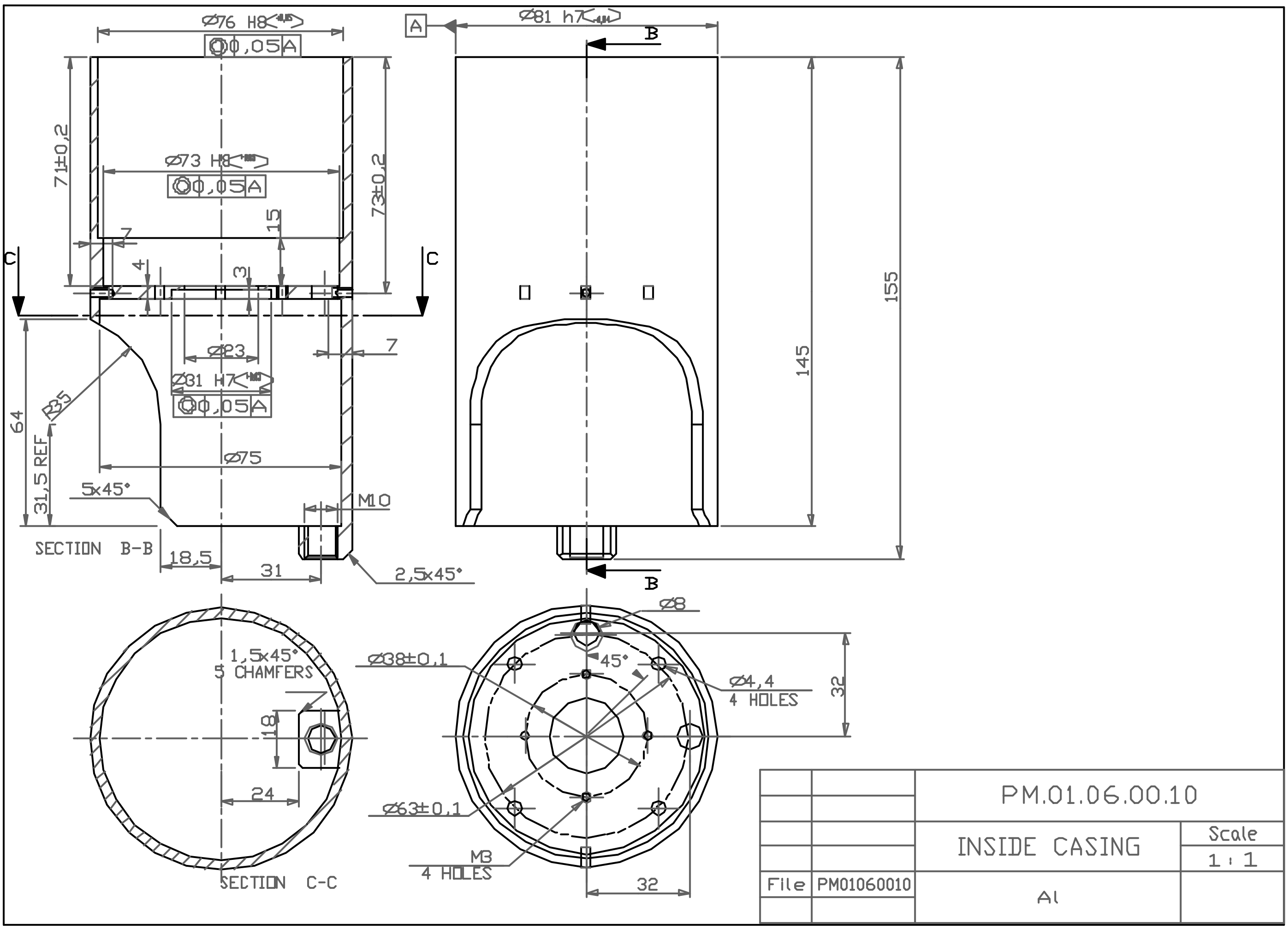
		PM.01.06.00.00	
		UPPERARM	Scale 1:1
File	PM01060000		Sheet: 2 of 2

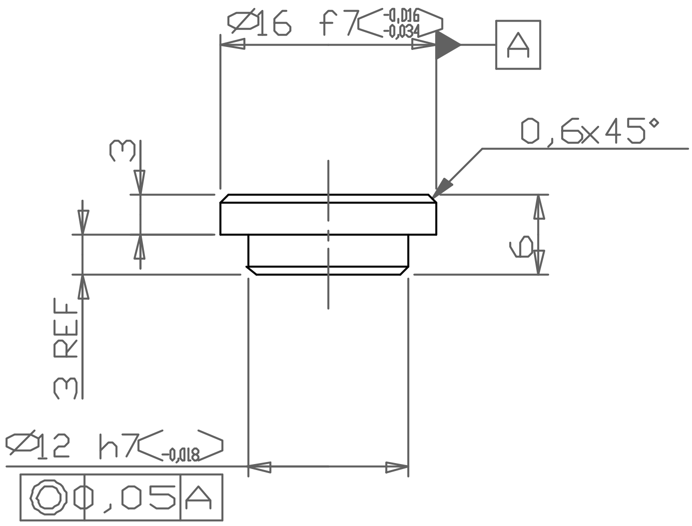


PM.01.06.00.01
OUTER CASING
Scale
1 : 1
File PM01060001
Al
SECTION C-C
SECTION B-B
SECTION D-D
M3
7 HOLES
5x45°
2 CHAMFERS
0,5x45°
2 CHAMFERS



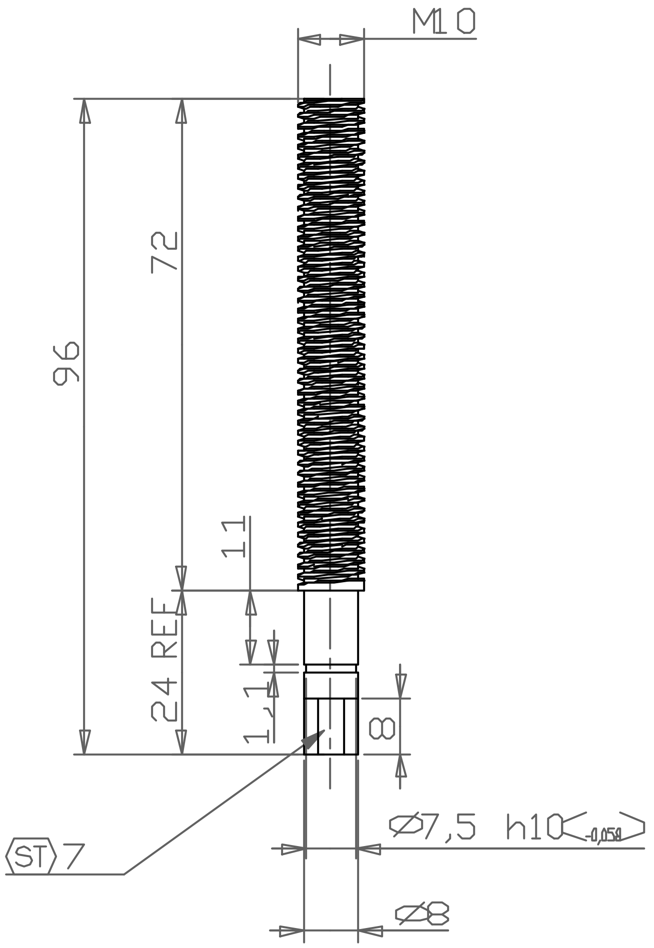
Ø74,2-0,2
Ø68±0,1
Ø61 h7(-0,03)
◎ 0,05 A
1,3
4
1
90°
2-0,2
Ø13
11
10
Ø55
49,5+0,3/-0,3
56,8
7
2,6
2,5
1,1
6,2
SECTION B-B
Ø9,6 h10(-0,058)
Ø10 h6(-0,009)
A
C
C
45°
Ø3,2
8 HOLES
22,5°
Ø3 H7(+0,01)
B
B
8,3
3+0,1/-0,1
SECTION C-C
PM.01.06.00.09
F/T AXLE
Scale
1:1
File
PM01060009
St45


SECTION B-B
SECTION C-C
1,5x45°
5 CHAMFERS
Ø38±0,1
Ø63±0,1
M3
4 HOLES
Ø4,4
4 HOLES
Ø8
45°
PM.01.06.00.10
INSIDE CASING
Scale
1 : 1
File
PM01060010
Al

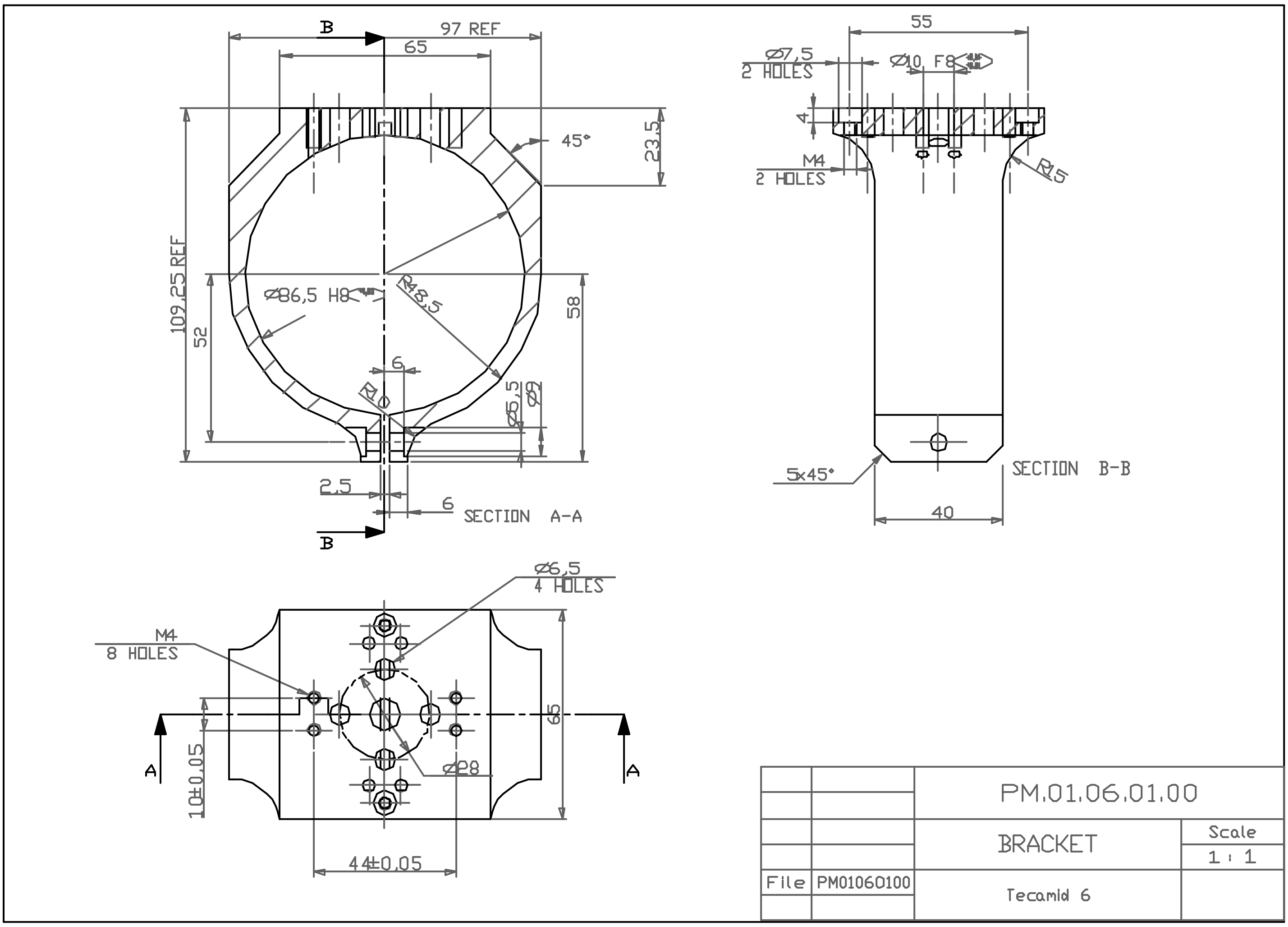


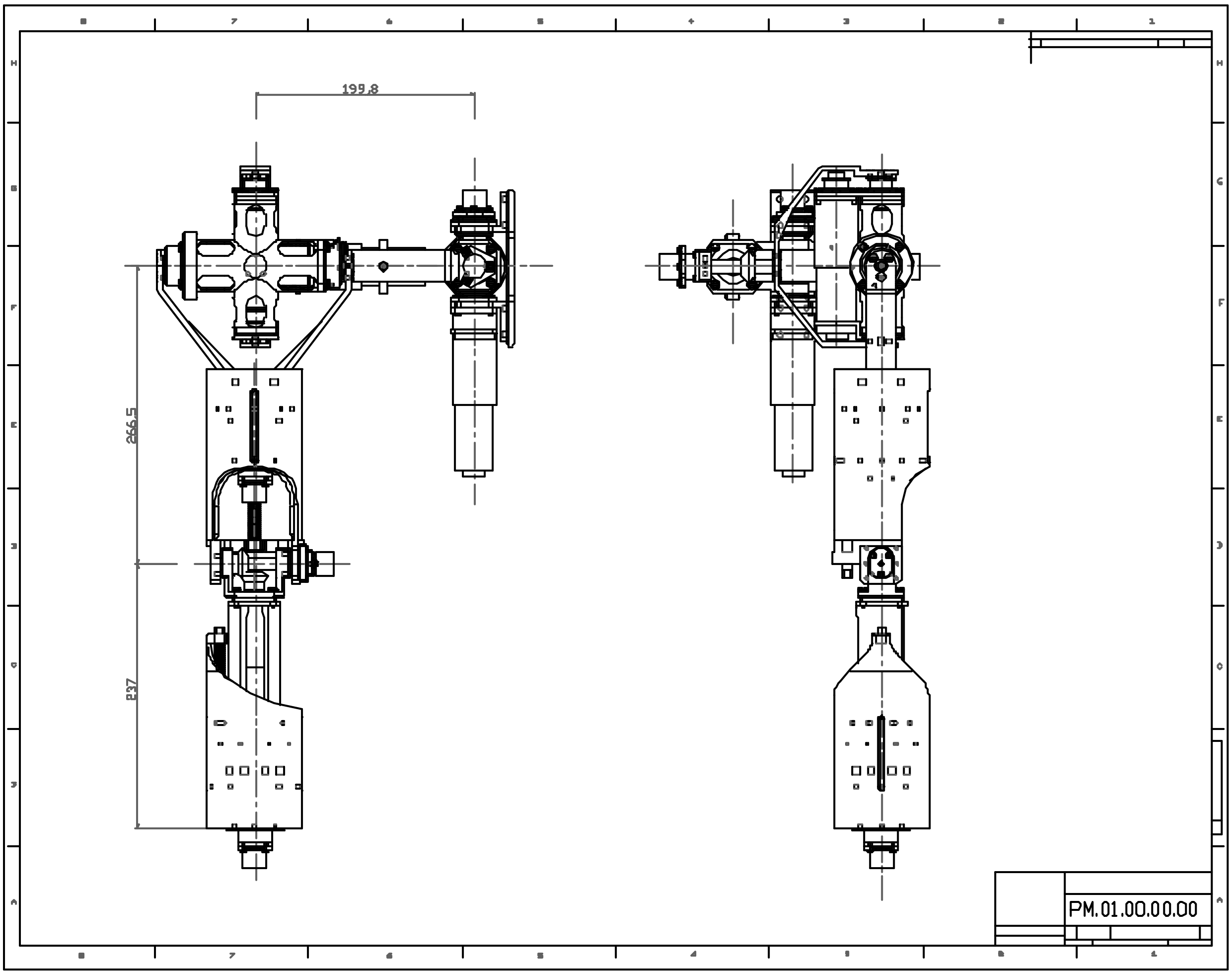
* Ø16f7 is fitted to F/T sensor
* Ø12h7 is fitted to Ø12H7 of FORK - PM.01.04.01.00

		PM.01.06.00.12	
		CENTER PIN	Scale
			2:1
File	PM01060012	Al	



		PM.01.06.00.19	
		ADJUSTMENT SCREW	Scale
			1:1
File	PM01060019	St45	


97 REF
65
B
45°
23,5
109,25 REF
52
58
Ø86,5 H8
R48,5
6
R10
Ø5,5
Ø9
2,5
6
SECTION A-A
55
Ø7,5
2 HOLES
Ø10 F8
4
M4
2 HOLES
R15
5x45°
SECTION B-B
40
Ø6,5
4 HOLES
M4
8 HOLES
A
65
10±0,05
Ø28
44±0,05
PM.01.06.01.00
BRACKET
Scale
1 : 1
File
PM01060100
Tecamid 6


199,8
266,5
237
PM.01.00.00.00

4. Algorithms for controlling the working mechanisms under modeling the resistances at the joints

Two possibilities are analyzed: creation of the resistance using a direct-current motor with built-in reduction gear (MR) and with an electromagnet brake.

Resistance modeling at the joint using MR.

A reduction gear with a two-directional transmission of the movement will be used. The torque Tx would be measured and the angle (?) of rotation around the same axis.
Initial position – robots grasp the orthosis at the initial position and start the movement into the direction + (positive). A functional converter is included at the control of the MR to be possible the creation of the resistance into two-directions of rotations at the joint and the change of the specifying torque depending on the value of the angle (?). Two functions would be realized:

Tdefined =sign? ?.T (4)

or

Tdefined =sign? ?.f(q) (5)

Principle of action

The direction of movement at the beginning of the cycle is + (positive), which defines a positive value of the specifying torque at the beginning of the movement. The MR should be rotated in – (minus) direction in order to be created that value at the joint because the resistance of the reduction gear will be not able to create the needed resistant torques.
The MR will reversing when will be reached the value T_{spec}=$T_?$ and as a result from the inertia of the system ?T will be minus value. The value $T_?$ is reducing under the new direction of movement (+). The MR changes its direction of rotating at ?T=0. A varitype regime will appear around the specified value T_{spec}.
It is expediently to be implemented a short area of insensibility (±e) or to be used a regulator with a more complex law of regulating in order to be reduced the variations during the movement. The described algorithm allows a zero resistance to be imitated at the joint and the MR should to overcome the resistance of the reduction gear. The direction of movement should be defined according the sign of increasing (? ?) of the coordinate. It is expediently to be formulated a threshold of distinction $d_?$ to be reduced the influence of the interferences over the working algorithm (including the vibrations) while defining the sign of ? ?. ? ? saves its sign from the previous step if |? ?|=0, while |? ?|>$d_?$ then D_{sign}= sign? ?. T_{spec} changes its sign during the change of the direction of the movement. The described algorithm gives a possibility to be imitated active movements for overcoming the external force acting, not exceeding the value of T_{spec}. The sign of T_{spec} should be changed at the control system in this case.

A reduction gear with a one-directional transmission of the movement will be used

The reduction gear instead of the motor at that case creates the resistant torque, which means that when is defined the direction of movement (defined from the sign of ? ?) the motor has to be rotated at the same direction when $T_?$>T_{spec}. There are two possible states of the motor during the movement at the defined direction – rotating in the same direction and motor shut off. The value of T_{spec} and the direction of the movement are defined as the previous case.

Some mistakes can occur, for example wrong defining the direction of movement and to be limited such regrettable effects there is a necessity to be applied a possibility to be stopped the procedure under exceeding $T_?$ over defined threshold value $T_{?thr}$. The procedure should be stopped when $|T_{?thr}|= T_{?thr}$ or a component from the force acting over the orthosis exceeds the specified threshold value.

Resistance modeling at the joint using a servo brake

The value of T_{spec} is always positive at this case and is defined using the dependences:

$$T_{spec}=T \text{ or } T_{spec}= + f(?)$$

The brake catches ($V_{br}=0$) at $|T_?| = T_{spec}$ and releases at $|T_?| > T_{spec}$ ($V_{br}=V_{supl}$). The modeling of zero resistance at the joint is not possible at this case. The resistant torque will be defined from the friction forces at the bearing unit at the joint and the brake while the brake is released. The brake will be always released at $T_{spec}=0$.

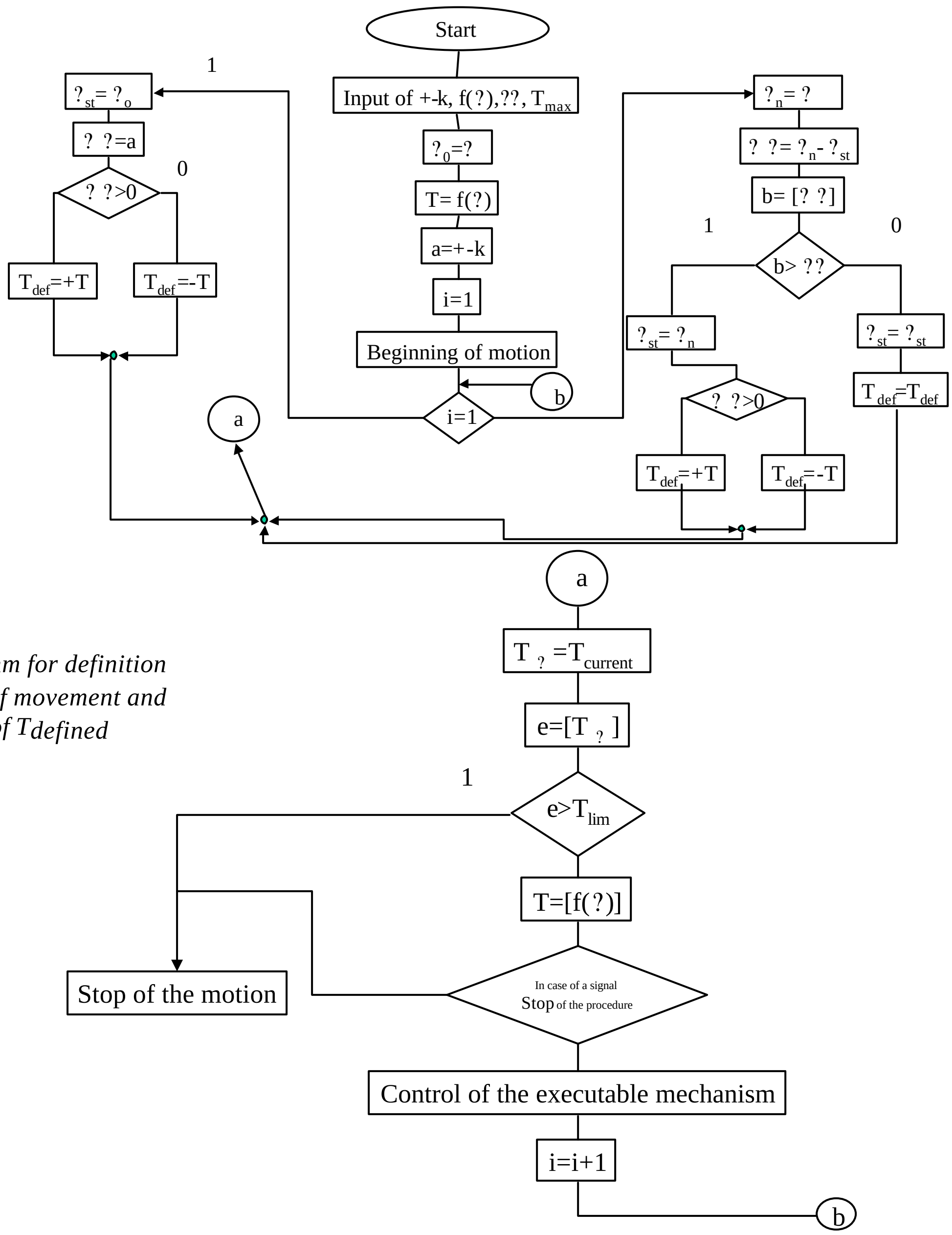


Fig.8 *Algorithm for definition the direction of movement and the sign of $T_{defined}$*

5. Structure and basic characteristics of the information - control system

The hardware and software base of the model's information – control system is divided responding to the functions which each of them execute. They could be differentiated into the following groups:

?? Proximate measurement and transformation of signals produced by the model. Those are analogue signals from the potentiomentric sensors of the joint coordinates; analogue signals from the force/torque sensors; digital signals from the switches and other signals from the REHAROB system. The transformation of those signals in digital description is organized in regime 'on-line';

- ?? Indirect receive in regime ‘on-line’ of values through elementary calculation procedures. Those values are related to the control of the executable mechanisms of the model. Those are for example the direction of change of the joint’s coordinate ?$_i$, the driving values of the controlled resistance torques $T_{i(defined)}$ upon the different coordinates, the current values of the resistance torques T_i which cannot be measured directly from the F/T sensors;
- ?? Control in regime ‘on-line’ with aim to imitate muscle resistance reactions (spasms);
- ?? Realization of calculation procedures in regime ‘off-line’ which are in relation basically to the following: further work up of the recorded model data; estimation of the robots motion repetition accuracy; calculation of the model joints’ F/T load;
- ?? Establishment of rehabilitation procedures database including the variation of the F/T loads and constrains;
- ?? Establishment of a dialog between the electromechanical model of the human arm and the other equipment of the REHAROB system and the operator.

The described functions require development of a hierarchic structure of the information-control system on three levels (Fig.9) – supervisory level, direct control level and field level. PC executes the highest functional level of the system. Those are functions related to the controlled values and processes, the Programmable Logical Controller (PLC), input of the executable regimes, dialog with the operator and the other REHAROB equipment, creation of database and other The second level executes functions related to formulation of the model direct control together with the work up of the signals produced from the sensors system. The third level has the function of sensors measurement and proximate control of the executable mechanisms.

6. Methods for simulation of muscle resistance

For the purpose of muscle’s resistance force simulation are used DC motors coupled with planetary gearboxes, which are built in the kinematics couples. The control system of the motor-gearboxes is presented on Fig.10. It uses a closed circle with feedback for the torque T_i, that is a result of external influence upon the axes of the kinematical couple. The defined values of $T_{i(defined)}$ must correspond to the desired value of muscle resistance which is in confrontations with the external reaction. $T_{i(defined)}$ is defined in a block for task formulation (BTF) as a function of the current value of the joint’s coordinate ?$_i$ and the consecutive number i of the rehabilitation procedure.

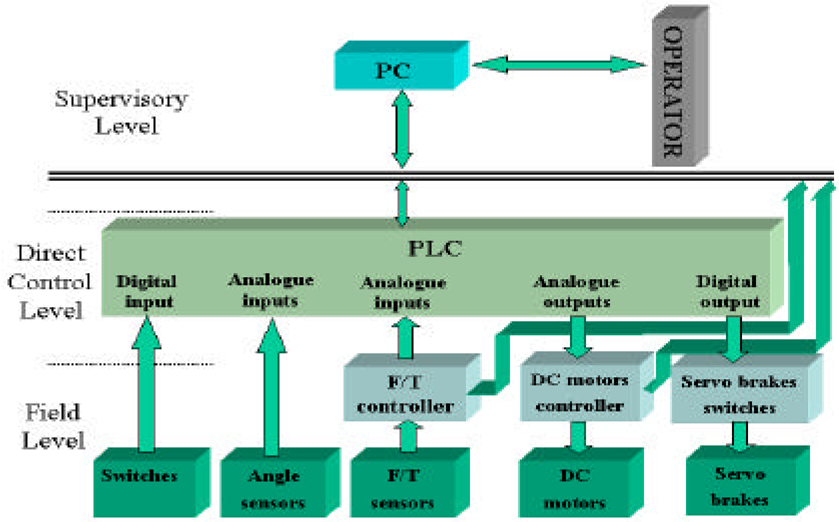


Fig.9

Hierarchical structure of the control svstem

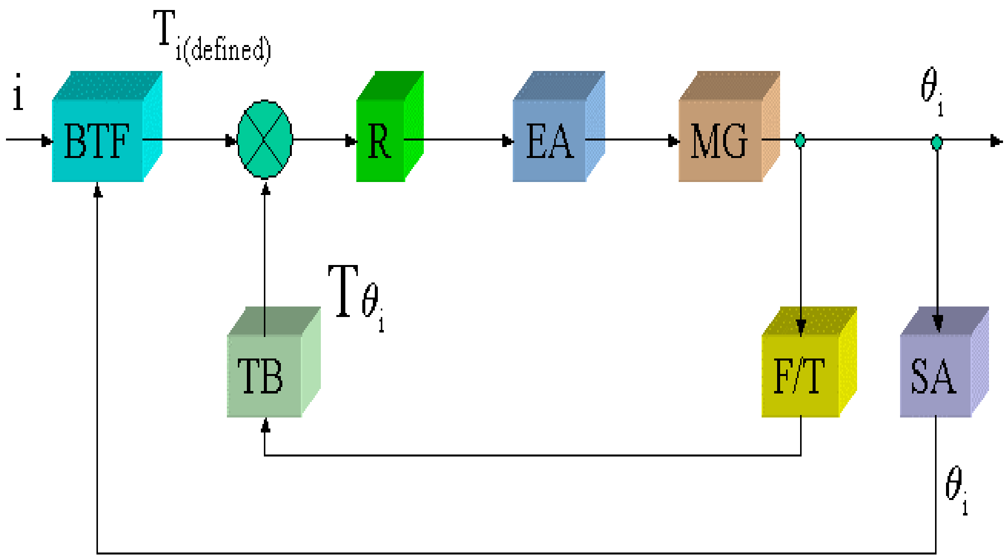


Fig.10
Schema of the system for formulation of controllable muscle reactions

(BTF- block for task formulation; EA – electronic amplifier; MG – DC motor coupled with gearbox;

SA – angle sensor; F/T force/torque sensor; TB – transformation block; R – regulator)

References:

Vitliemov V., Mladenov M., Bratanov D. – Electromechanical model of upper human limb, Assistive Technology Research Series Volume 9, Integration of assistive technology in the information age, ICORR'2001 7th International Conference on Rehabilitation Robotics. 2001 Evry, France, pp 117 – 122

Appendix I

Photos of the manufactured parts and some of the commercial components

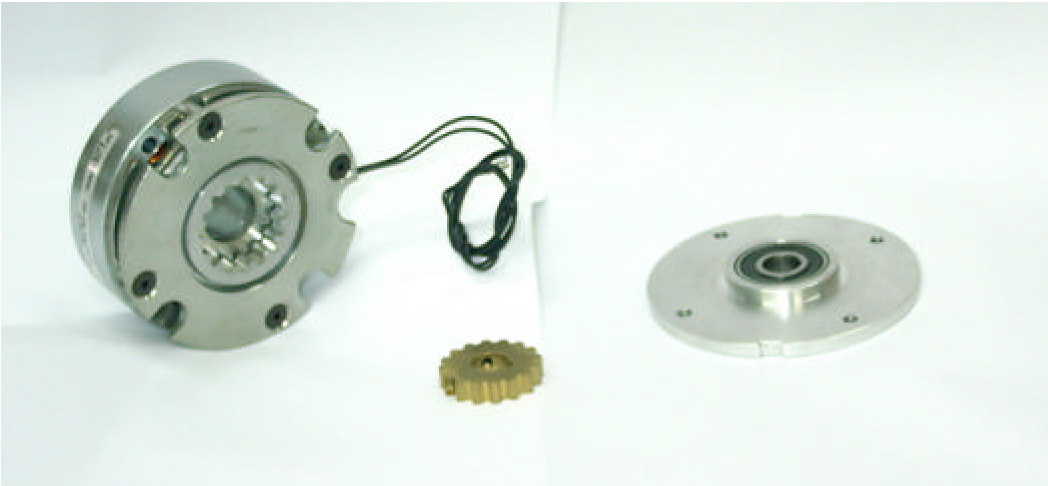


Photo 1 – Servo brake & mounting plate

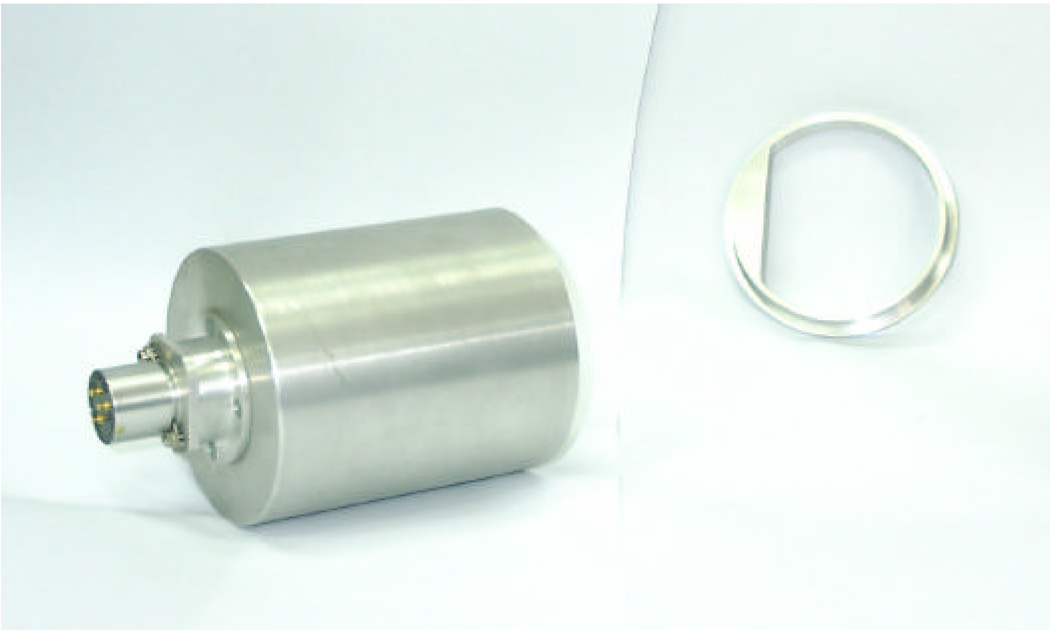


Photo 2 – Inside casing of the forearm

Photo 3 – DC Motor – gearbox with attached cone gears

Photo 4 – Clavicle joint

Photo 5 and Photo 6 – Cross yoke

Photo 6

Photo 7 – DC Motor-gearbox

Photo 8 – 6-component Force/Torque sensor

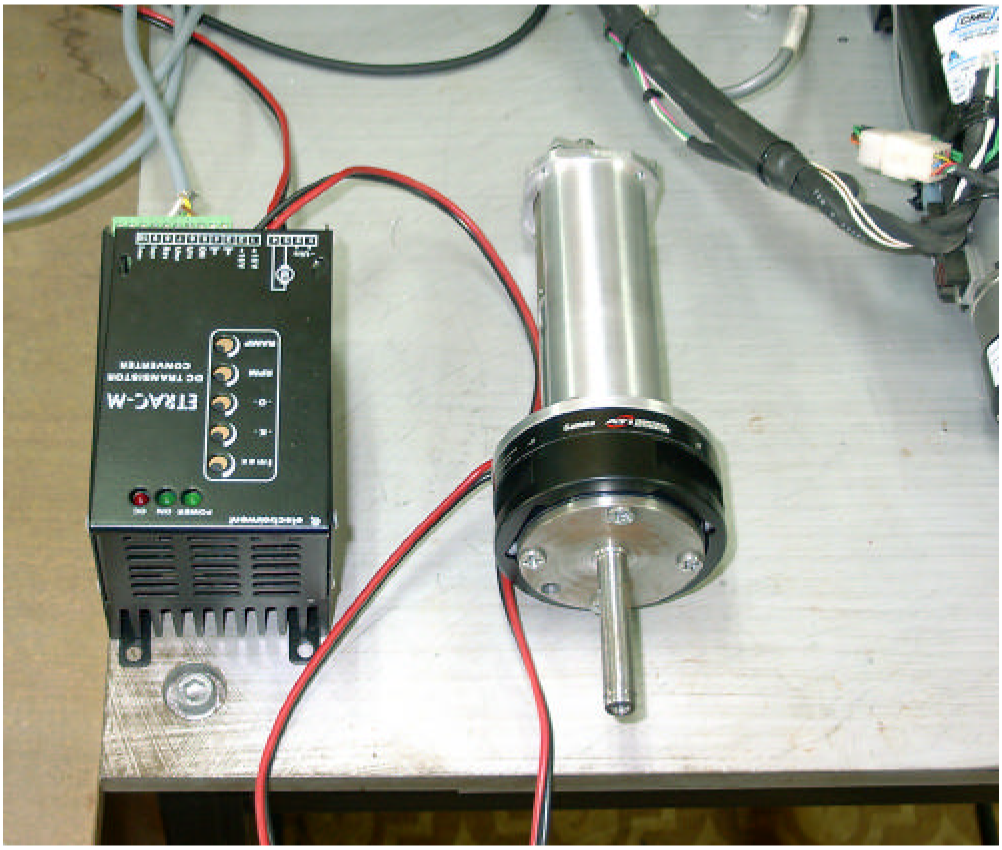


Photo 9 – The base of the assembled forearm with the DC motor controller

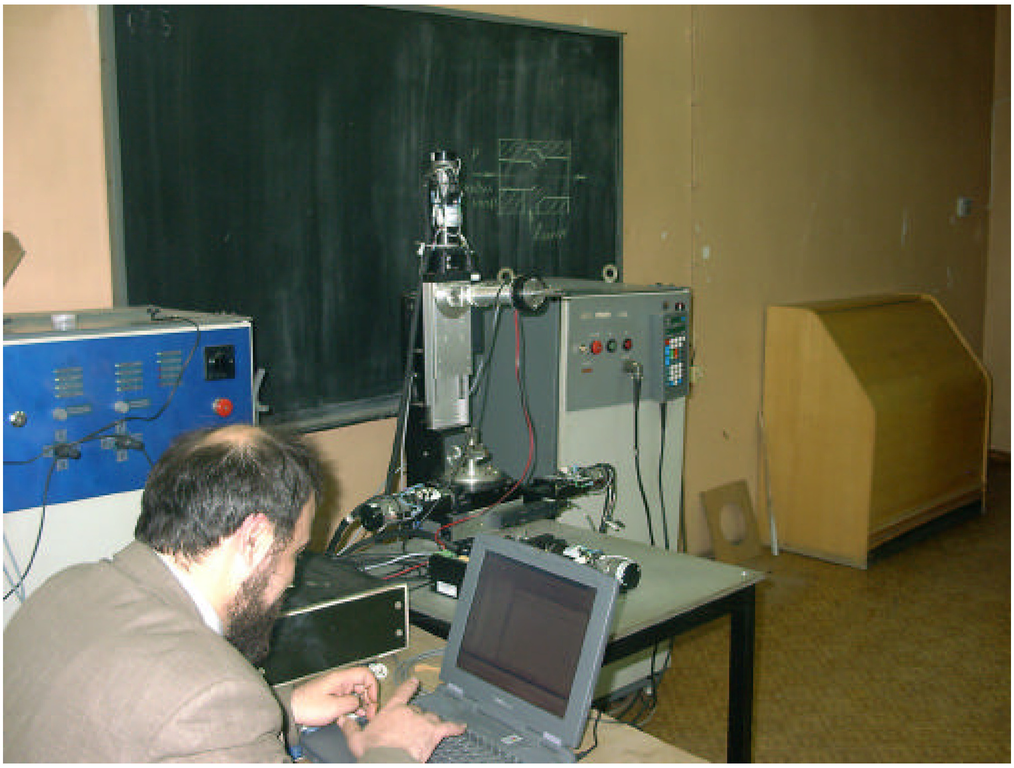


Photo 10 and Photo 11 – Test and setup of the forearm control

Photo 11 – The forearm attached to the test-bed