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PU	Public	
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Abstract:
In order to meet the objectives of workpackage WP1 it has been designed a prototype of bio-inspired robot eye, which could be used for the analysis of ocular motion and its interplay with vision both within the scope of WP1 and also within other workpackages and in view of the integration activities planned as final demonstration of the project's results. This robot-eye has been designed like a platform to realize the human ocular motion and vision.
This document describes the various modules that compose the robot-eye, in particular the mechanical components of the robot and their assembly procedure are described. Furthermore the actuation system and the control architecture that drive the eye are described. This robot-eye prototype can be easily integrated with the vision modules developed in the other workpackages.

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1 Executive Summary

This document contains the design of a bioinspired robot eye which constitutes the Delivrable 1.4 entitled *Bioinspired Stereovision Robot System* (*Preliminary version*) of the EU Project EYESHOTS. Deliverable 1.4 is part of the workpackage WP1: *Eye movements for Exploration of the 3D Space*. In particular this document is the first *outcome* of the activities of the worktask **Task 1.3** *Bioinspired Stereo Vision Robot System*.

The workpackage WP1 is devoted to the study of ocular mechanics and oculomotor control, for both single eye and conjugate movements. The target is to investigate how mechanics of the eye plant affects the strategies implemented by the brain to drive typical biological motions ocular motions (including saccades and smooth pursuit). A second goal is the study of the geometric and kinematic effects of ocular motions on image flow, for supporting the estimation of 3D information from ocular motions. Finally, from the engineering point of view the major expected achievement is to develop a bio-inspired stereoscopic robot system capable to emulate the ocular motions to be used during the planned experimental tests.

This prototype of a robot-eye has been designed on the geometrical and mechanical analysis made with the simulation tool of bioinspired ocular models described in the Deliverable D1.4a (*Bioinspired Stereovision Robot System. Robot Prototype Prototype*).

This device can be used for the analysis of ocular motion and its interplay with vision both within the scope of WP1 and also within other workpackages and in view of the integration activities planned as final demonstration of the project's results. It also possible perform comparative analysis with the common pan-tilt platforms (used by UJI partner) commonly used in robot vision.

The main requirements of this prototype are the dimensions close to the human, the capability to replicate the human ocular movements and the human vision performance.

This document describe in detail all the mechanical components which form the robot and others used for the assembly. A description of the embedded miscrocamera is given which has small size and high performance. Furthermore the actuation system that drive the eyeball is described, and the control architecture (that define the ocular movements) is presented.

2 Introduction

This document decribes the design of a bio-inspired stereo-vision robot with the mechanics and motion characteristics of a human eye.
Many eye-head robots have been developed in the past few years, and several of these are common *pan-tilt* systems, where a camera rotates about *pan-tilt* axes.
The main goal of this work is twofold: 1) to provide the guidelines for the implementation of a tendon driven robot, 2) to emulate the different types of human eye movements for binocular vision experiments.
In fact the robot-eye prototype can be easily integrated with the vision algorithms, developed in the other workpackages, to realize the human ocular motion and human-like vison exeperiments.
Like the human eye the robot must obey to the laws (*Listing's Law* and *Half-Angle Rule*) [2], [3], [4] which specify the geometric and kinematics charatheritics of the human eye movements. Indeed the geometry of the robot prototype is based on the model described in [6] and the mechanical properties (viscosity and elasticity) of the eye plant are considered [4], [5].
Relevant characteristics are also the dimensions of the robot-eye that are very close to the human eye. The size have been due to various trade-offs during the selection of the components available on-the-shelf (e.g. the eyeball, motors, on board camera etc).
The first part of this document will focus on the description of the mechanical structure of a prototype of humanoid robot eye. In particular the eyeball with the vision system and the support structure for the eyeball and the actuation system will be described.
In the second part the actuation system (which emulates the human extraocular muscles) wiil be described. The actuation is performed by tendons, i.e. thin stiff wires, pulled by force generators (DC motors). Finally in Section control system architecture we will analyze the various modules involved in the control of the ocular movements and in which way they comunicate.
The Appendix A contains the list of the main components that form the stereo-vision robot system. The appendices from B to D contains the drawings (with dimensions) of the mechanical components of the robot-eye, instead in the appendices from E to J there are the datasheets of the microcamera, lens, actuators and controllers, cables and connectors.

3 Robot Eye Design

In this Section the mechanical structure of a prototype of humanoid robot-eye is described and the design details of the various modules and subsystem are analyzed.
This prototype of a robot eye must emulate the mechanical structure and the motions of a human eye with a comparable working range.
This robot eye has approximately the shape of a truncated cone where the larger diameter and smaller ones are respectively 34 and 45 mm, with an overall lenght of 120 mm. The robot has been designed by assuming that the eyeball is a sphere with three rotational degrees of freedom about its center, and the actuation system driving the eyeball is a combination of linear motors, springs and tendons. Each linear motor has two springs in parallel; the motor and the springs are connected to the eyeball through the tendons. The three dimensional CAD model of the bio-

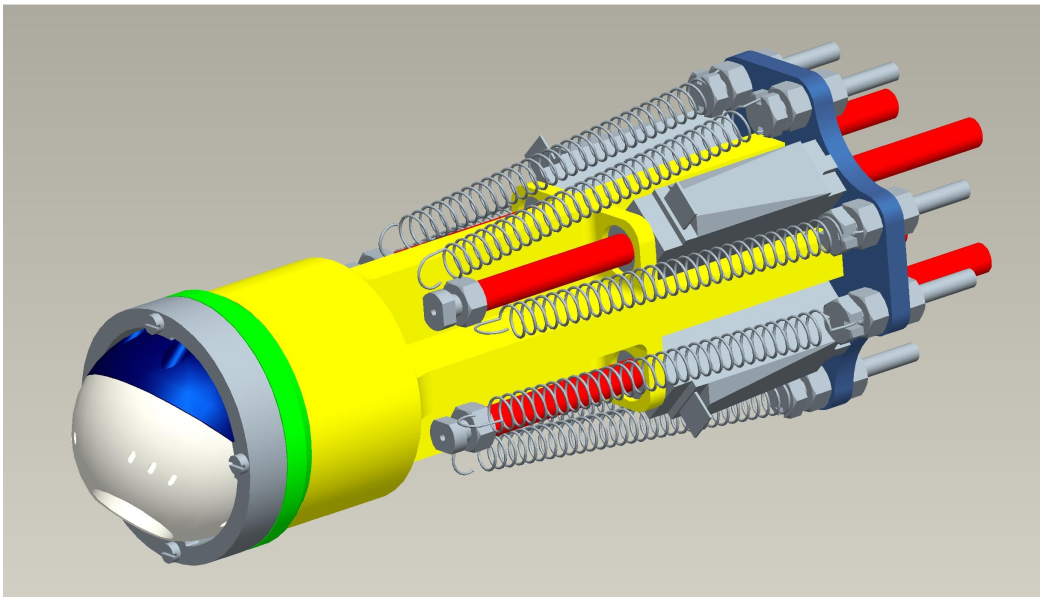


Figure 1: 3D model of the prototype of humanoid robot eye.

inspired robot eye (the tendons are not shown)is shown in Figure 1.
As it appears in Figure1 the motors are in a oblique position, in this way it is possible to place the two springs in parallel to the motor and give a compact shape to the robot eye.
The robot-eye prototype is composed of different modules and subsystems (Figure 2). The main componets of the robot-eye are:

- the eyeball with the vision sytems (CMOS microcamera and lens),

- the supporting structure (eyeball support, frame, front flange, rear flange),
- the actuation system (linear motors, springs and tendons),
- the control system architecture (industrial drives, I/O boards, real-time operating system).

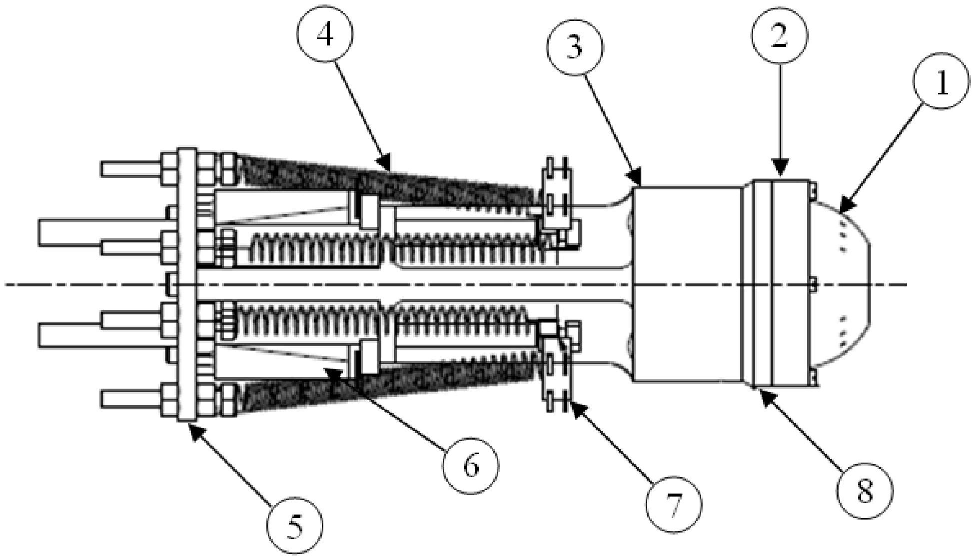
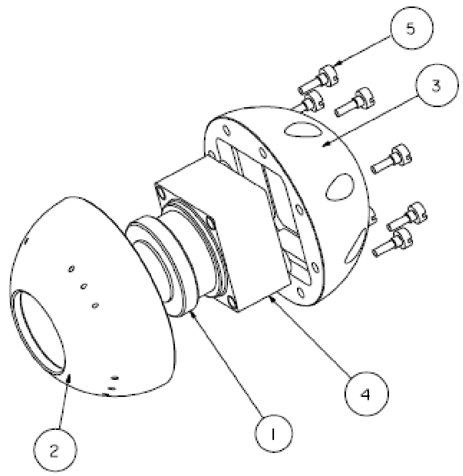


Figure 2: Lateral view of the eye robot prototype and its modules: 1 Eyeball, 2 Front flange, 3 Frame, 4 Spring, 5 Rear flange, 6 Linear motor, 7 Position sensor, 8 Eyeball support.

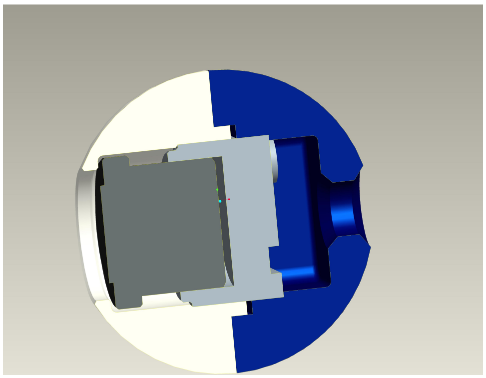
All these modules will be described in detail in the next sections.

4 The Eyeball

The eyeball (Appendix A) is a precision DELRIN sphere with a diameter of 28 mm. The sphere has been divided in two parts: anterior half eye and posterior half eye. These two parts are machined to host the vision system (commercial CMOS microcamera, Appendix G, and optic, Appendix H) and to route camera power supply, video and control signal cables (Appendix J) to the external electronics. In Figure 3 the explosed view and the section of the 3D CAD model of the eyeball are shown. The posterior half eye (Figure 5) is machined to host the CMOS mi-



(a)



(b)

Figure 3: (a) Exploded view and components of the eyeball: 1 Lens, 2 Anterior half eye, 3 Posterior half eye, 4 CMOS Camera, 5 Screw . (b) Section of the 3D CAD model of the eyeball.

crocamera and a micro PCB board (with a board to board connector, Appendix I used to interface the video signal cables with the on board camera. On the camera

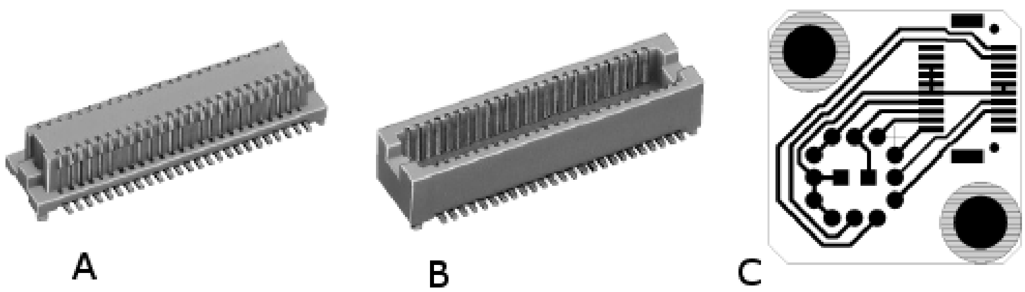


Figure 4: Board to board camera connectors: (a) Receptacle connector (PCB board side). (b) Header connector (camera side).

side there is a 20 pin *header* connector (Hirose DF12E3.5-20DP-0.5V), instead

on the PCB board side there is a 20 pin *receptacle* connector (Hirose DF12E3.5-20DS-0.5V, Appendix I) where the video signal cables are welded. The video signal cables are twelve miniature cables (produced by Vishay) with a teflon insulation, shield and conductors are made of silver plated copper.
On the posterior half eye there are eight holes (∅ 1.4 mm) for the screws that lock the posterior half eye to the anterior half eye, and another hole (∅ 5 mm), to route the video signal microcables out to the eyeball.

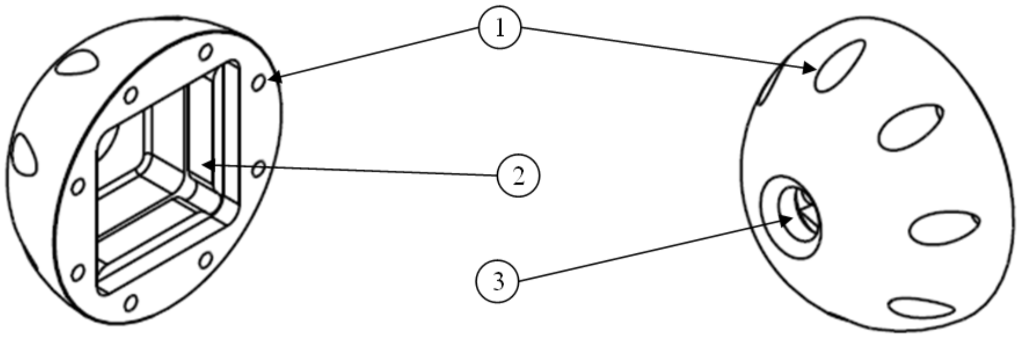


Figure 5: External and internal view of the posterior half eye module: 1 Screw holes, 2 Lens housing , 3 Video signal microcables hole.

The anterior half eye (Figure 6) has four set of three holes. For each set of holes the central one is the insertion point for the tendon attached to the linear motor and the two lateral holes are the insertion points for the tendons attached to the springs in parallel to the motor.

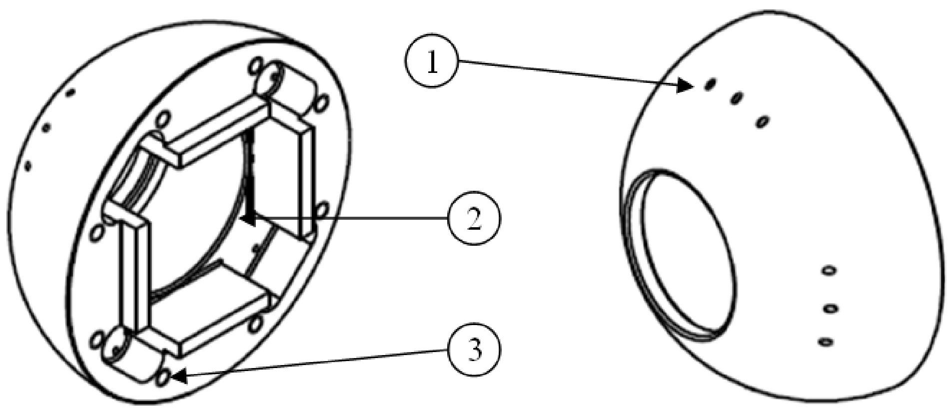


Figure 6: External and internal view of the anterior half eye module: 1 Motor and springs insertion points, 2 Microcamera housing, 3 Screw holes.

4.1 CMOS camera

In this Section we will analyze the main characteristics of the embedded digital camera (EDC) hosts by the eyeball. The main requirements for the EDC are:

- commercial camera that belongs to the class of WEB-Cam devices,
- very small dimensions and weight,
- USB 2.0 comunication interface,
- low number of power supply and video signal cables,

The commercial EDC that match all this characteristics is the MU9PC-MH micro-camera (Appendix G), shown in Figure 7, produced by SOFTHARD Technology Ltd.

Figure 7: MU9PC microcamera.

The MU9PC Camera is a micro-camera with a resolution up to 5M (Color), a CMOS image sensor and a USB 2.0 Interface. The camera has its own drivers for XP/Vista/W7, both x86 and x64, all drivers are certified by Microsoft.
The MU9PC Camera Core specifications are in the following list:

- Resolution: up to 5M 2592x1944 pixels,
- Frame rate: up to 232 Frm/s 320x240 pixels,
- Sensor Type: CMOS RGB Bayer Matrix,
- Sensor Model: APTINA MT9P031,
- Sensor Size: 1/2.5 inch,

- Sensor Active Area: 5.7 x 4.28 mm,
- Image Data Interface: USB 2.0,
- Data I/O: GPIO 2IN, 2OUT, Serial Port,
- Power Requirements: 5V USB, typ. 0.6W,
- Lens Mount: M12.

The housing of the MU9PC Camera is made of aluminum, the height, the width and the depth of the camera are respectively 8.5, 15 and 15 mm with a total weight of 3.6 g (without lens). In Figure 8 are shown the top and the bottom side and the lateral view of the CAD model of the MU9PC microcamera.

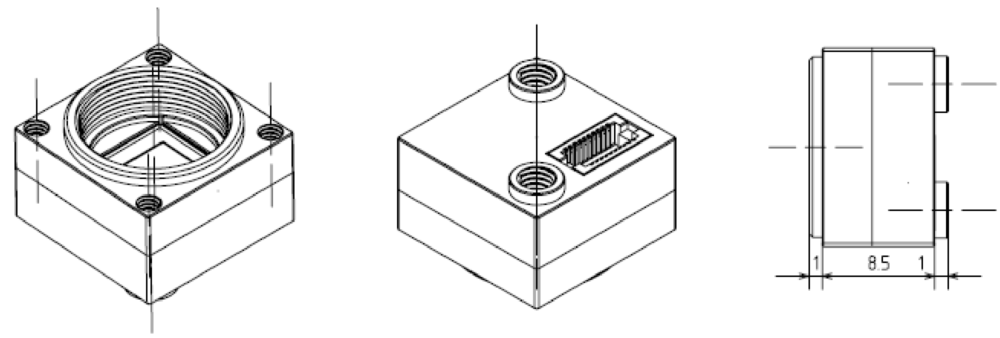


Figure 8: The top and the bottom side and the lateral view of the CAD model of the MU9PC microcamera.

4.2 Camera lens

The MU9PC microcamera (Appendix G) is provided without the lens. The lens that we have chosen are produced by *Sunex Inc.*. In the previous Section we have seen that the camera has an image format of 1/2.5 inch, thus we need a lens with this image format. This isn't a common format and it is diifcult to find a lens with this format and with small dimensions. Furthermore there is a minimun order quantity (>100) for this kind of lens. For this reasons we have chosen a lens with an image format of 1/2 inch (*DSL853* lens, Appendix H).
Note that to have a good image resolution it is necessary to cover the entire image area, to do this the lens image circle (image format) must be equal or greater then the imager diagonal.
The DSL853 lens is a multi-element glass lens, with a total weight of 2.6 g, optimized for CMOS imager with 1/2 inch format. It is especially suited for building

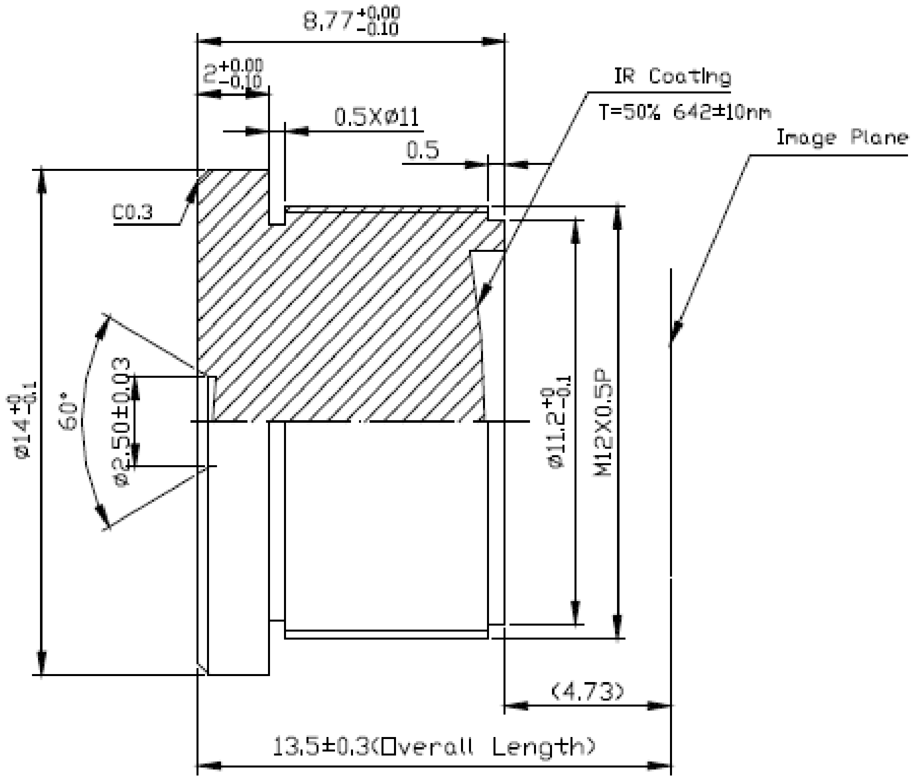


Figure 9: CAD model of the DSL853 lens.

low-cost, compact digital cameras because of the lowp rofile property of the lens design. In Figure 9 is shown the CAD model of the DSL853 lens.
The key features of the DSL853 lens are:

- low profile: optical path length $<$ 13.5 mm from lens front physical surface to the image plane,
- all glass elements: compatible with outdoor environment,
- dual-mode aperture F/3.2: long depth of focus, optimized for focus operation,
- high image quality,
- low-cost.

Optical specifications of the DSL853 lens:

- imager resolution: 1/2",

- focal lenght: 8.0 mm,
- max. Image Circle: 8.6 mm,
- diagonal field of view: 56.2 deg,
- total path lenght: 12.9 mm.

5 Supporting Structure

The structure (Appendix C) designed to support the eyeball, the motors and the springs is composed of four distinct components (shown in Figure 10 and described below):

- eyeball support: a low friction support designed to hold the eyeball and to implement the pointwise pulleys,
- frame: a structure cross, attached to the eyeball support, to hold the motors and the springs,
- front flange: an anterior flange to lock the eyeball on the eyeball support,
- rear flange: a posterior flange to lock the motors and the springs on the frame,

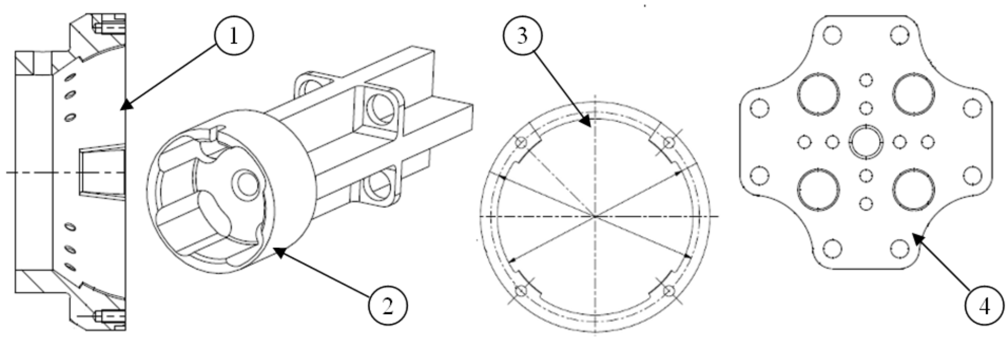


Figure 10: CAD model of the supporting structure: 1 Eyeball support, 2 Frame, 3 Front flange, 4 Rear flange.

5.1 Eyeball support

The *eyeball support* (Appendix C) module holds the eyeball, it is made of TEFLON and has the major function of implementing the pointwise pulleys. The pulleys route the actuation tendons and they ensure the correct mechanical implementation of Listing's Law [2], [3], [4].

The position of the pointwise pulleys is simmetrical with respect to the position of the insertion points on the eyeball (see Section 4). On the *eyeball support* there are four groups of three pulleys: the central for the tendon attached to the linear motor and the two lateral for the tendons attached to the springs.

In Figure 11 a sketch of the posterior and two different lateral views of the eyeball

support is shown. In this picture the holes of the pointwise pulleys and the holes for the screws that lock the front flange module on the eyeball support are highlighted.
The eyeball support is glued on the front of the frame.

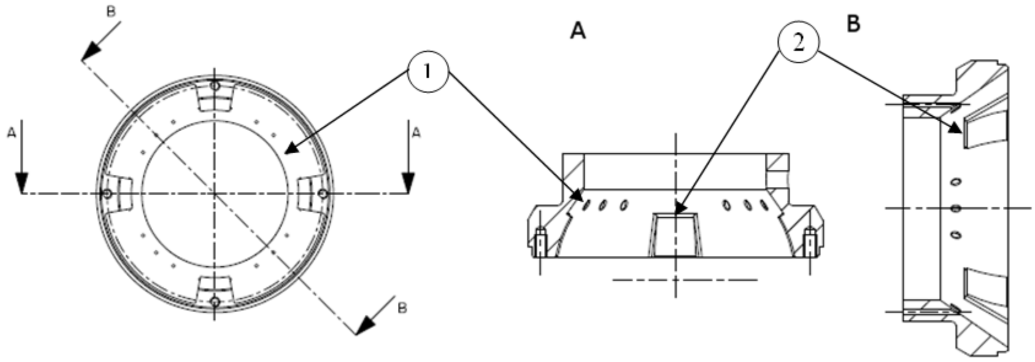


Figure 11: CAD model of the eyeball support: posterior and two lateral view (A,B). Where: 1 Pointwise pulley holes, 2 Screw holes.

5.2 Frame

The *frame* (Appendix C) module is the central structure of the robot system and is made of aluminum. The frame has a cross shape and its main function is to support all the modules, that compound the robot, and the linear motors.
In Figure12the three dimensional, lateral and posterior views of the frame module are shown . The cylinder on the front side of the frame has four holes, in this way

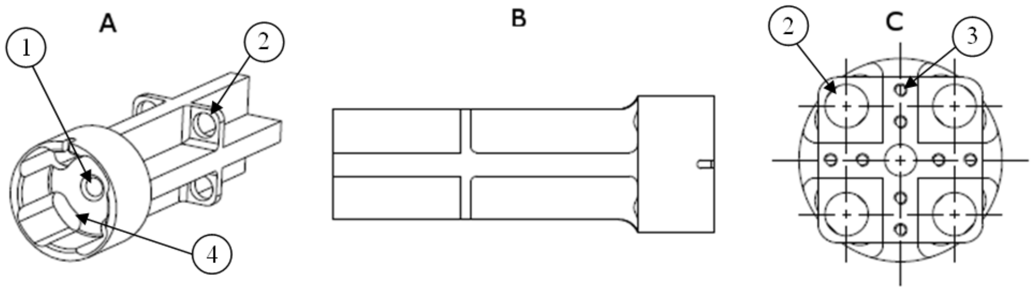


Figure 12: CAD model of the frame: 3D (A), lateral (B) and posterior (C) views. Where: 1 Hole for the power supply and video signal cables, 2 Central flange with the holes for the rods of the linear motors, 3 Screw hole, 4 Hole for the rod of the motor in the front of the frame.

the rods of the linear motors can reach the extent necessary to cover the working range of the robot eye comparable with the working range of the human eye.

In the rear side of the frame there are eight holes for the screws that lock the rear flange on the frame.
In the center of the frame there is a flange with four holes for the rods of the linear motors. The four motors are locked on the frame between this central flange and the rear flange.
From the front to the rear of the frame there is a hole to route the power supply and video signals microcables from the on board camera to the external eletronics.

5.3 Front flange

The *front flange* (Appendix C) module is made of TEFLON. This module is a flange with a ring shape used to lock the eyeball on the eyeball support.
In Figure 13 is shown a sketch of the front flange where are highlighted the four holes for the screws that lock the front flange on the eyeball support.

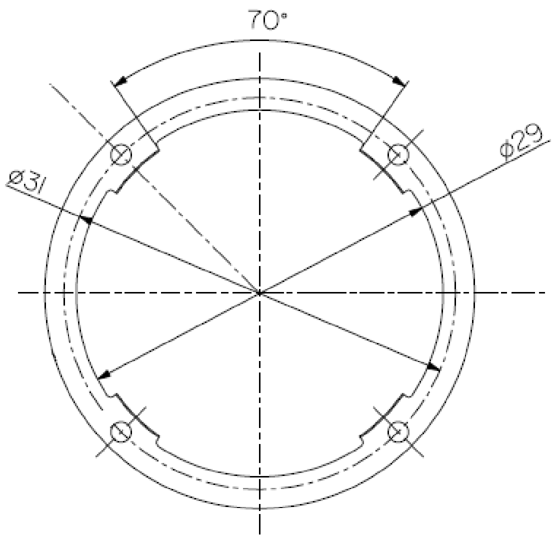


Figure 13: CAD model of the frontal view of the front flange.

5.4 Rear flange

The *rear flange* (Appendix C) module is made of aluminum and its shape is optimized to occupy minimum space.
The major functions of the rear flange module are to lock the four linear motors on the frame and to sopport the springs (connected to the eyeball trought the tendons).
In Figure 14 there is a sketch of the rear flange module.

As we can see in this figure there are four holes (2) that allow the elongation of the rods of the motors out of the frame, eight holes (1) for the screws where are attached the springs and other eight holes (3) for the screws that lock the rear flange module on the frame.

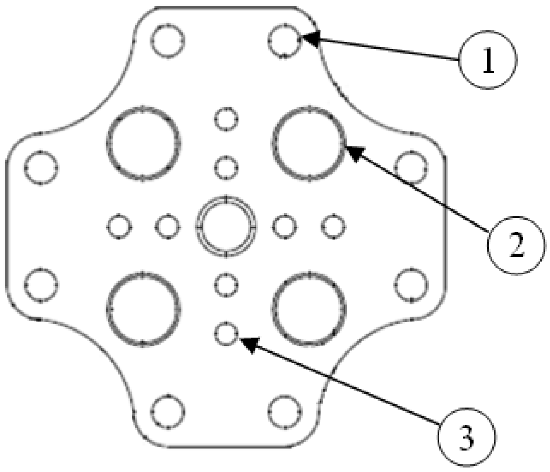


Figure 14: CAD model of the rear flange: frontal (A) and lateral (B) views. Where: 1 Spring screw holes, 2 Motor rod holes, 3 Holes for the fixing screws.

6 Assembly Procedure

In this Section the steps to assemble the various mudules (see previous section) that compose the robot eye and the modules used for the assembly will be described. Assembly procedure:

- the eyeball (Appendix B) is hold fixed by a suitable frame and the tendons are locked in the insertion points on the anterior half eye,
- the tendon clamps (Figure15, Appendix D) are srewed on the rods of the linear motors,

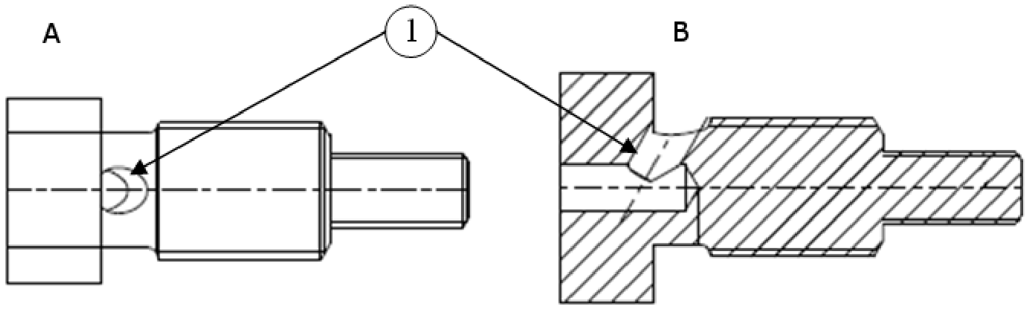


Figure 15: CAD Model of a tendon clamp: A Lateral view, B Section. Where: 1 Tendon hole.

- the eyeball support is glued on the frame,
- the four linear motors are mounted and locked (with the rear flange) on the frame (Appendix C),
- the eyeball is inserted in the eyeball support (Appendix C), the tendons are inserted in the poinwise pulley holes, and locked on the eyeball support with the front flange (Appendix C),
- four tendons are connected to the four motors throught the tendon clamps,
- the spacers (Figure 16 A, Appendix D) are inserted in the rods of the motors that come out from the rear flange,
- the washers (Figure 16 B, Appendix D) are mounted on the rods of the motors that come out from the rear flange and are locked on the rods with the screws,
- the zero gauge (Figure 16 C, Appendix D) module is mounted on the fron side of the robot eye,

- the pivot gauge (Figure 16 D, Appendix D) is inserted in the hole in the zero gauge and in the anterior half eye.

At this point the eyeball (and thus the CMOS Camera) is aligned with the axis of the frame. After that:

- the tendons are pulled and locked in the tendon clamps,
- the eight springs are mounted on the rear flange with the M3 screws and connected to the spring tendons.
- the modules zero gauge, pivot gauge, washers and spacers are removed,
- the springs are trimmed.

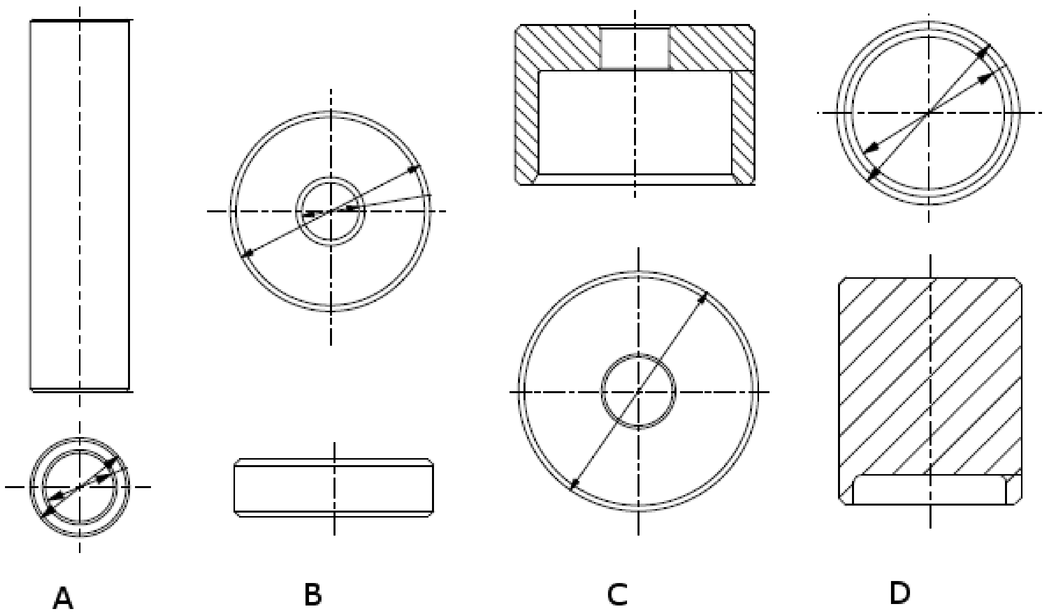


Figure 16: CAD Model of the assembly modules: A Spacer lateral and frontal views, B, Washer frontal and lateral views, C Zero gauge section and frontal view, D Pivot gauge frontal view and section.

7 Actuation System

The actuation system is composed of four tendons, four force generators (DC brushless linear motors, Appendix E) and eignt springs.
The tendons are thin stiff wires, connected to the rods of the motors and to the springs on one side and to the eyeball on the other side. The actuators pull the tendons and drive the movements of the eyeball. There are two springs in parallel to each motor that pull the tendons in the opposite direction with respect to the motor one. The main funcitons of the springs are to emulate the elasticity of the orbit of the human eye and to restore the *zero* position (primary position) of the eyeball when the system isn't actuated. The tension of the springs, and thus the restoring force that act on the eyeball, can be regulated through the screws that support the springs.

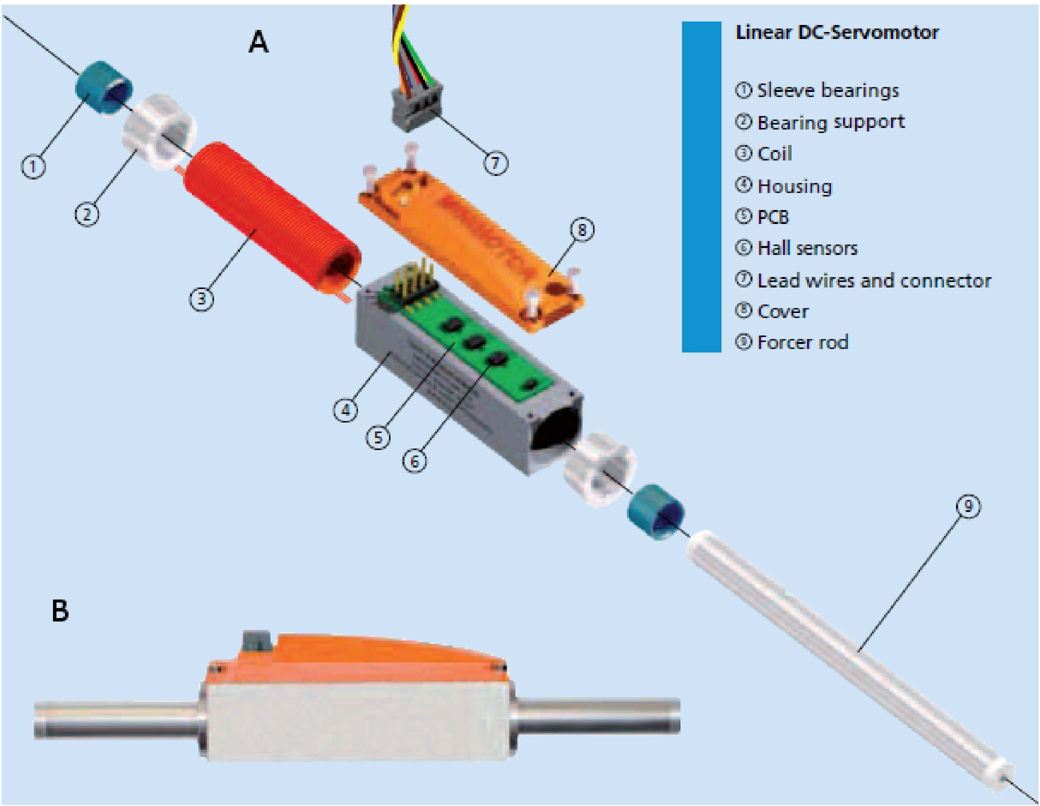


Figure 17: The LM0830 Faulhaber DC linear motor: A Explosed view of the linear motor, B linear motor

The actuators chosen for the robot eye are linear DC servomotors (LM0830-040-01) produced by Faulhaber. This new type of motors combines the speed and the robustness of a pneumatic system with the flexibility and reliability features of

an electro mechanical linear motor. The absence of residual static force and the excellent relationship between the linear force and the current make these motors ideal for use in micro-positioning applications like the robot eye. In Figure 17 are shown the linear motor (B) and the explosed view of the linear motor (A). This actuator provide a linear motion of the tendons with a small stroke (40 mm, in the current implementation, and less 20 mm for an eye of human size) [1] and limited pulling force. In fact this motor produce a continuous force of 1,03 N, with an acceleration of 147.8 m/s^2 and a speed of 2.4 m/s^2 [2]. Furthermore this linear motor ensures a very low error in repeatability and precision (respectively 40 and 140 μm) of the rod movement and thus of the robot eye ocular movements.
The linear motors are equipped with analog Hall sensors providing the main feedback for the control of the ocular movements.

[1] Indeed for the eyeball with 28 mm of diameter a stroke of 21 mm is sufficient to cover the working range but the linear motor is sold with a stroke of two sizes: 15 and 40 mm.

[2] theorical value, referring only to the motor.

8 Control system architecture

The control system architecture is implemented as a three level hierarchical structure (Figure 18). At the highest level there is the *Host PC* with a common Win-

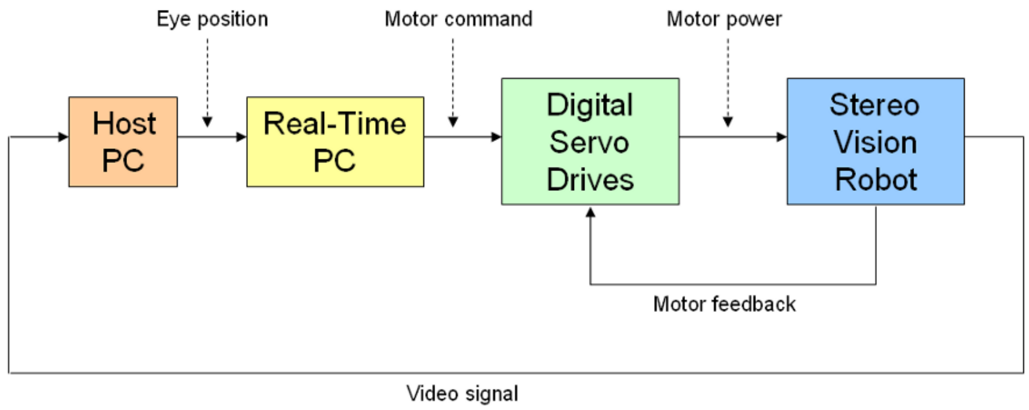
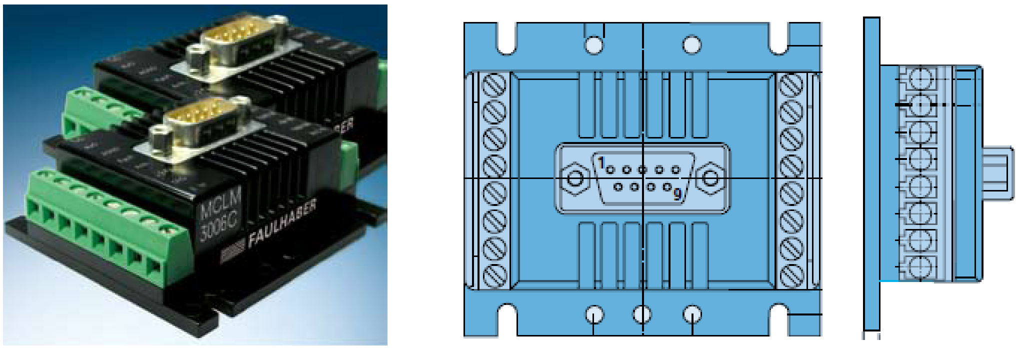


Figure 18: Sketch of the control system architecture for the stereo vision robot

dows XP operating system. Here is insatalled a Simulink (MATLAB Toolbox) algorithm that acquires and processes the video signal and computes the reference eye position (eye movement) sent to the next level.
After thet, at the *Real-Time PC (Target PC)* level, the four motor commands are computed from the input reference eye position. The Real-Time PC is a mchine with installed the *xPC Target* real-time kernel and a set of I/O boards to comunicate with the next level (*Digital Servo Drive*, Appendix F). The xPC Target product (MATLAB Toolbox) is a solution for prototyping, testing and running real-time applications using standard PC hardware. In our case on the Target PC runs, in real-time, the Simulink model with the algorithm that computes the motor commands.
A CAN board (CAN-AC2-PCI), mounted on the Target PC, send the motor command messages to the digital servo drives with the CANOpen comunication protocol. A Ethernet card is used to acquire the reference eye position via TCP/IP messages.
At low level there are four digital servo drives (MCLM 3003/06 C), one for each motor, with implemented a PI control loop to control the motor command inputs. This type of controller is designed for linear DC-Servomotors with linear Hall sensors. This motion controller is based on a high performance digital signal processor (DSP), which enables tight control (velocity control, velocity profile, positioning mode), precise positioning and very low speeds. On the device there is a CANOpen interface for integration in a CAN network with transfer rate up to 1Mbit/s and comunication with the Target PC throught the CANOpen communi-

cation protocol.



(a) (b)

Figure 19: (a) Picture of the MCML3003/06C. (b) Frontal and laterla views of the MCML3003/06C.

The dimension of the MCLM3003/06C controller are very small: 65, 58 and 27.5 mm respectively for width, depth and height.
With the Motion Manager software the communication parameters can be configured, and the auto tuning of the PI controller parameters can be executed.

9 Conclusions

This is a starting point to realize a bioinspired robot-eye. During the design of the robot-eye prototype the mechanical characteristics of the human oculomotor plant (eyeball, orbital tissue, soft pulley) and the geometrical assumptions (insertion points, pointwise pulleys) ensuring the mechanical implementation of the Listing' Law and the Half-Angle Rule have been considered.
Furthermore using the linear motors, tendons and springs it is possible emulate the four recti extra-ocular muscles. Thus this prototype is completely different from a common pan-tilt vision system (used by UJI group), where the actuation acts on the joints (instead of the body) and on a pan-tilt camera it is impossible implements the two ocular laws.
On the robot eye it is possible realize eye movement (saccadic, smooth pursuit, vergence), and stereo vision exeperiments, in fact this system can be easily integrated with the various vision modules developed by UG, KU Leuven partners.

References

[1] D. Tweed, T. Vilis, ”Geometric relations of eye position and velocity vectors during saccades”, Vision. Res., vol. 30, n. 1, pp. 111-127, 1990.

[2] A. D. Polpitiya and B. K. Ghosh, ”Modeling the Dynamics of Oculomotor System in Three Dimensions”, Proceedings of the Conference on Decision and Control, pp. 6418-6422, Maui,Dec. 2003.

[3] L. Koornneef, ”The first results of a new anatomical method of approach to the human orbit following a clinical enquiry”, Acta Morphol Neerl Scand, vol. 12, n. 4, pp. 259-282, 1974.

[4] A. T. Bahill, J. R. Latimer and B. T. Troost, ”Linear homeomorphic saccadic eye movement”, IEEE Trans. Biomed. Eng., vol BME-27, no. 11, pp 631-639, 1980.

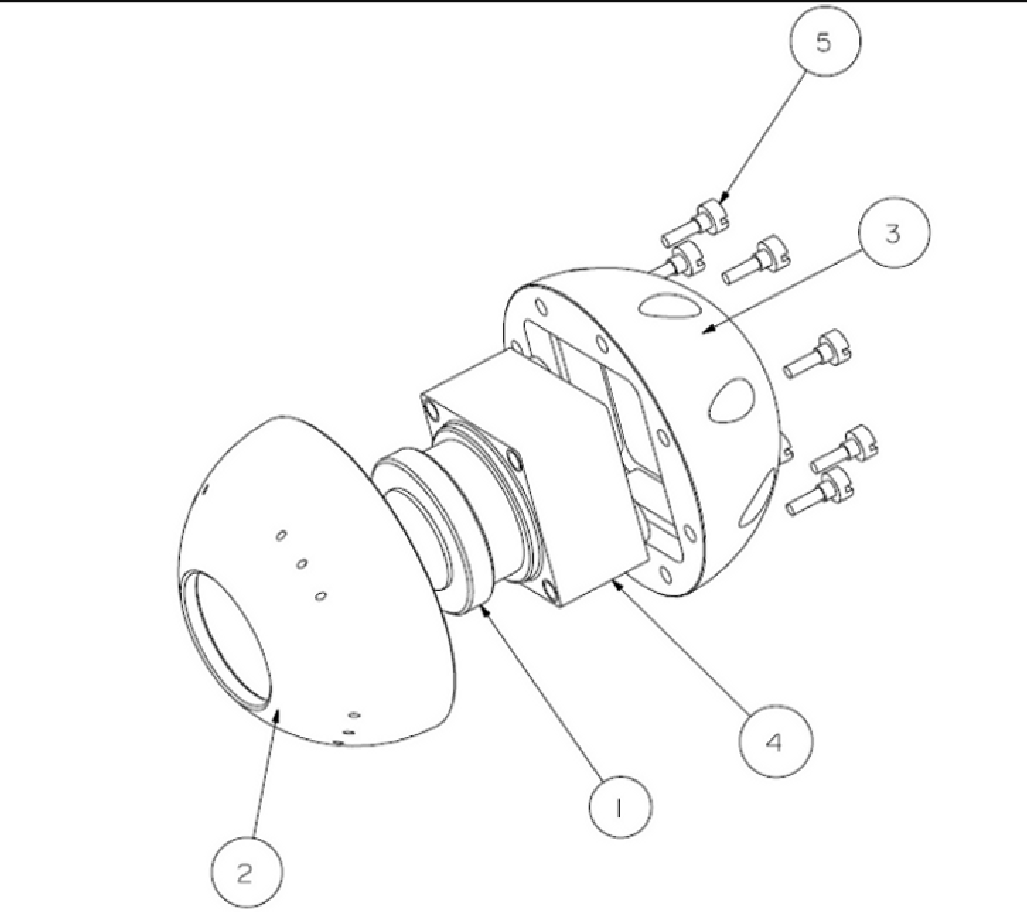
[5] J. D. Enderle, J. W. Wolfe and J. T. Yates, ”The linear homeomorphic saccadic eye movement model- A modification”, IEEE Trans. Biomed. Eng., vol BME-31, no. 11, pp 717-720, 1984.

[6] G. Cannata and M. Maggiali, ”Models of the Design of Bioinspired Robot Eyes”, IEEE Transaction on Robotics, 2008, vol.24 (no.1).

A Bill Of Material (BOM)

Product	**Description**	**Vendor**	**Quantity**
MUP9PC	Micro 5M Color CMOS Camera with USB 2.0 Interface.	SOFTHART Technology Ltd.	1
DLS853	Compact DSC Lens For CMOS Imager.	Sunex Inc..	1
LM0830-040-01	Linear DC-Servomotor.	FAULHABER.	4
MCLM3003/06C	Digital servo drive.	FAULHABER.	4
L08.90.02	Flexboard adapter.	FAULHABER.	4
STC-36T-12	Miniature cable.	Vishay.	1
DF12E3.5-20DS-0.5V	Board to board receptacle connector.	Hirose.	1

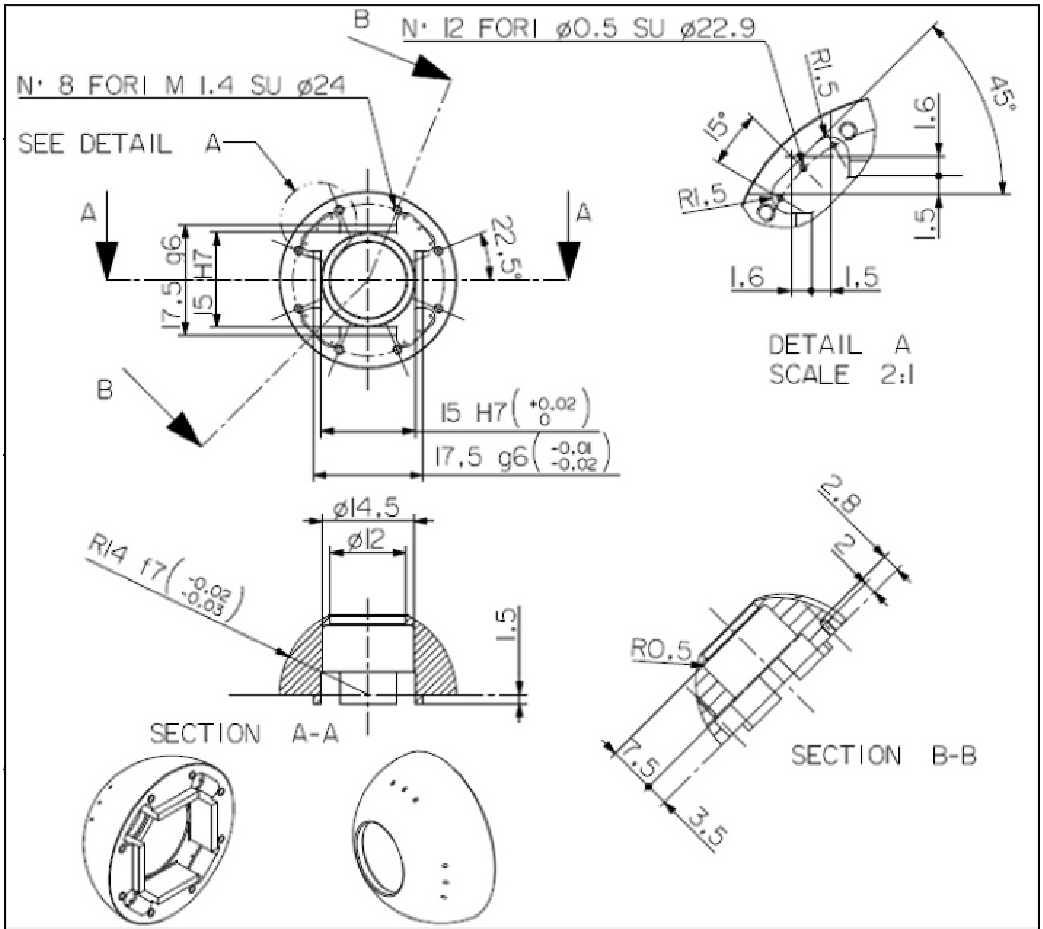
B Eyeball Design (003A0001)



Pos.	Codice / Numero disegno	Descrizione	QTA
5	VI-4-4--_-_U6107_C	VITE TCI UNI 6107 M 1.4X4	8
4	MU9PX	TV CAMERA	I
3	003P0010	SEMI OCCHIO POSTERIORE	I
2	003P0001	SEMI OCCHIO ANTERIORE	I
I	LENS	OTTICA	I

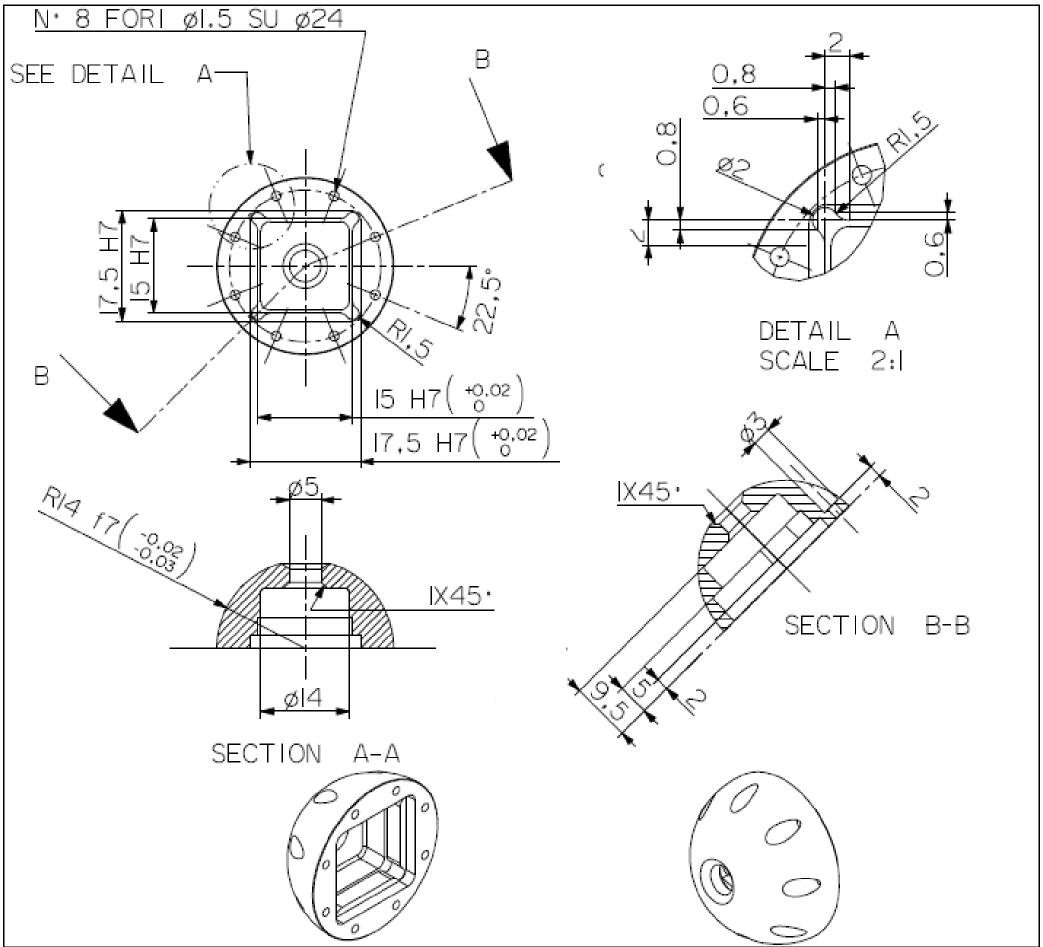
	Disegnato	F. Orzelli	Peso	0,023
Assieme principale	003A0002			
Sottoassieme	--			
UNIVERSITA' di GENOVA DIMEC PMARLab	PALLA OCCHIO		Scala	2:1
			Data	18-Jul-10
	Disegno n°	003A0001 Rev 0	Foglio	1/1

Anterior half eye Design (003P0001)



N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
1	DELRIN	--	R=0.2	0.2 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2	Filett.metriche ISO	
	1.6	Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	0,007
Assieme principale	003A0002			
Sottoassieme	003A0001			
UNIVERSITA' di GENOVA DIMEC PMARLab	SEMI OCCHIO ANTERIORE		Scala	1:1
			Data	18-Jul-10
	Disegno n°	003P0001 Rev 0	Foglio	1/1

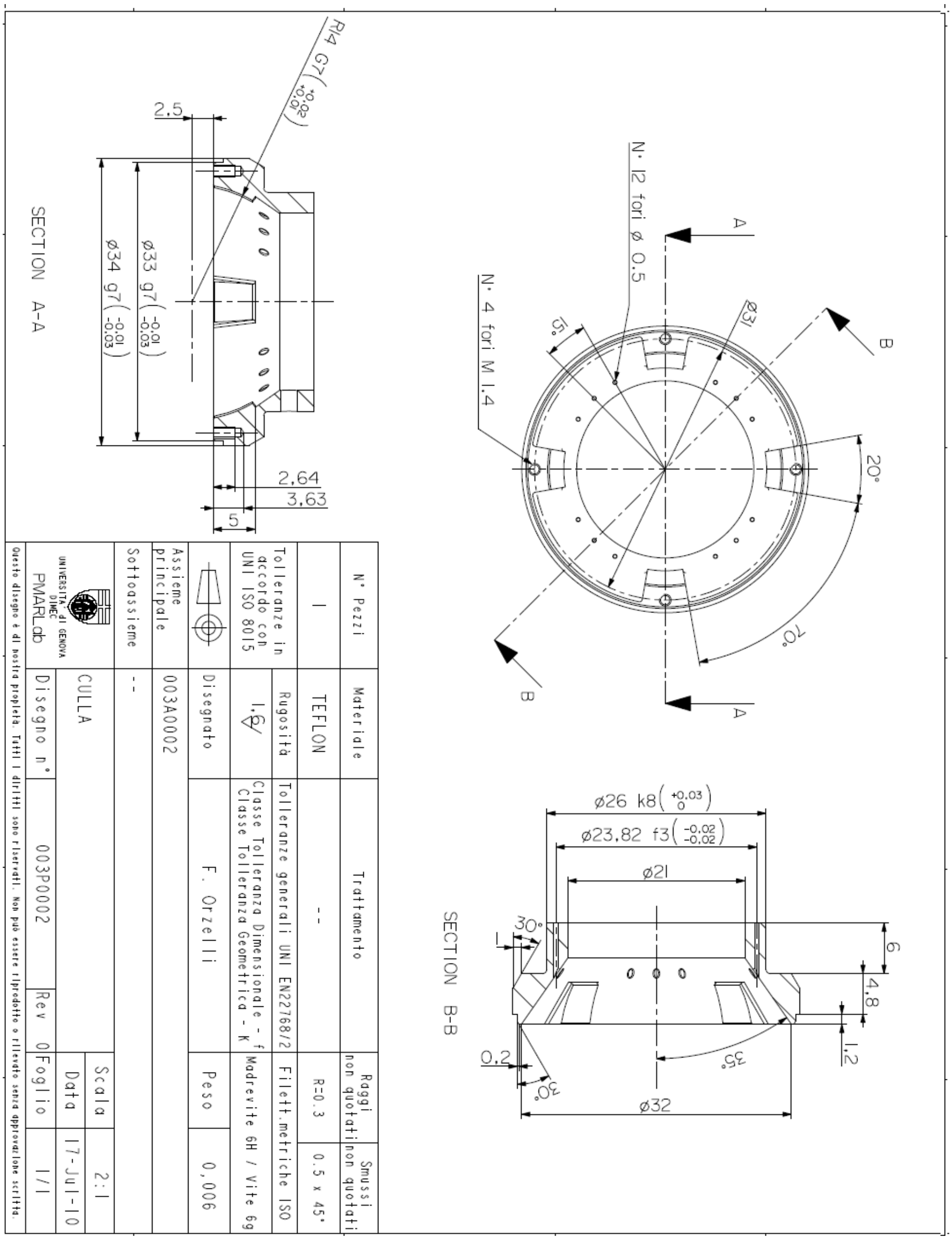
Posterior half eye Design (003P0010)



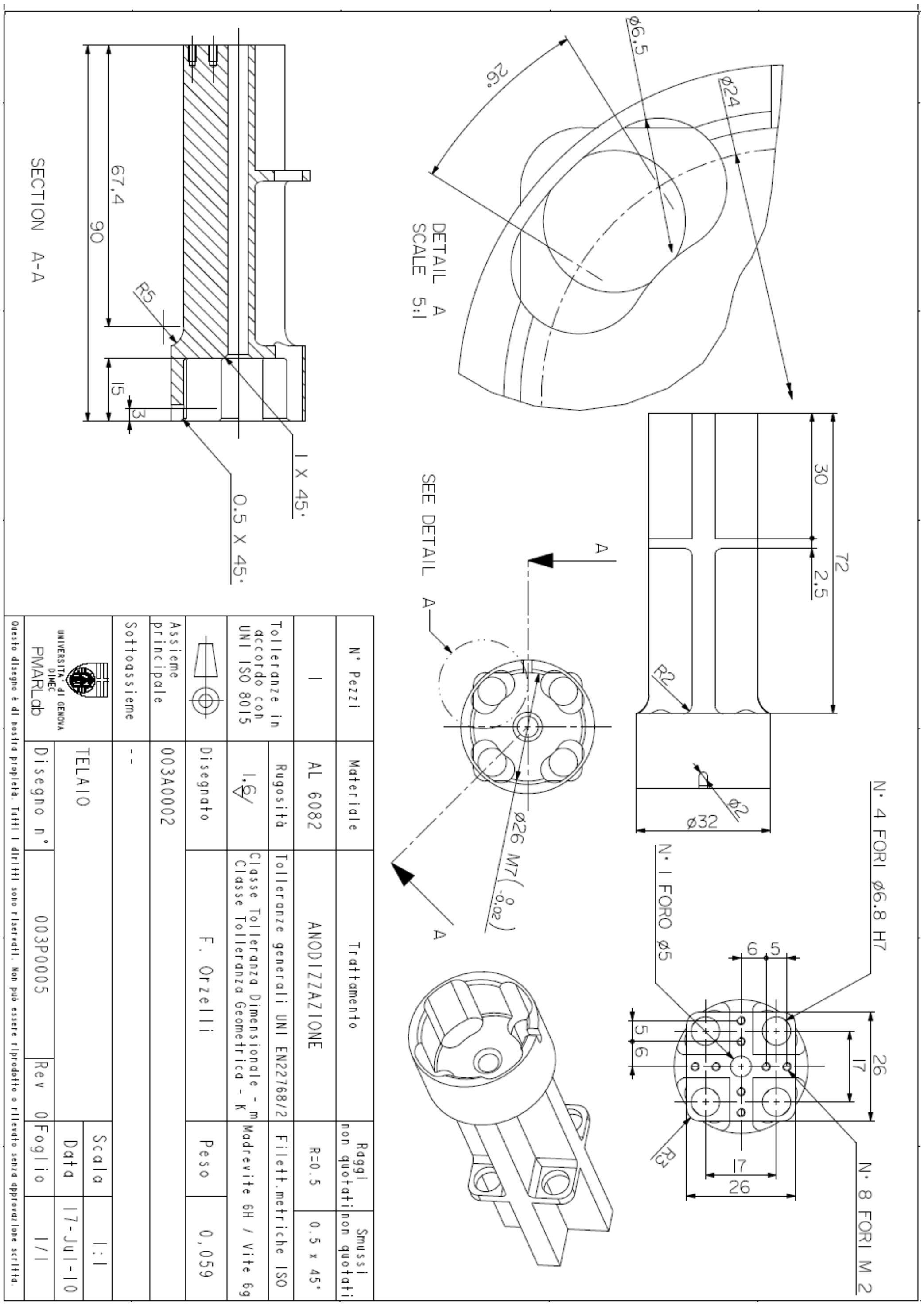
N° Pezzi	Materiale	Trattamento		Raggi non quotati	Smussi non quotati
1	DELRIN	--		R=0.2	0.2 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2		Filett.metriche ISO	
	1,6	Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K		Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli		Peso	0,007
Assieme principale	003A0002				
Sottoassieme	003A0001				
UNIVERSITA' di GENOVA DIMEC PMARLab	SEMI OCCHIO POSTERIORE			Scala	1:1
				Data	18-Jul-10
	Disegno n°	003P0010	Rev 0	Foglio	1/1

C Supporting Structure Design

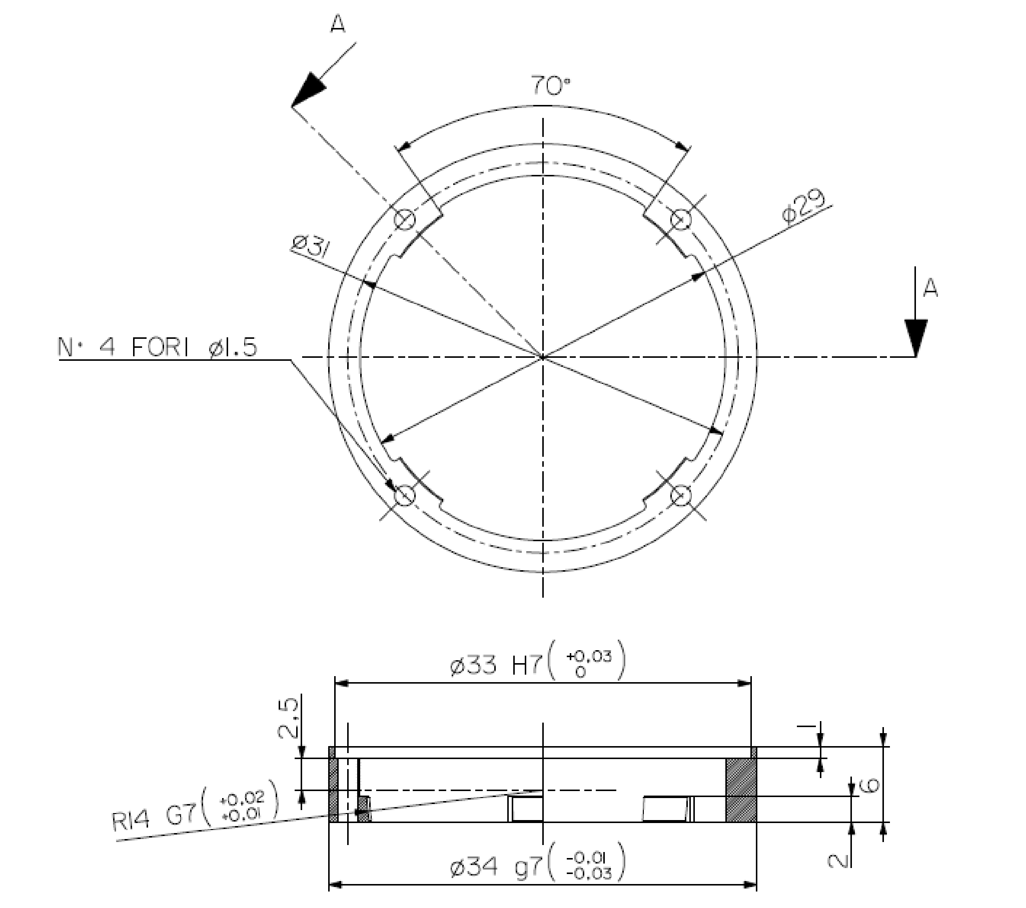
Eyeball Support Design (003P0002)



Frame Design (003P0005)

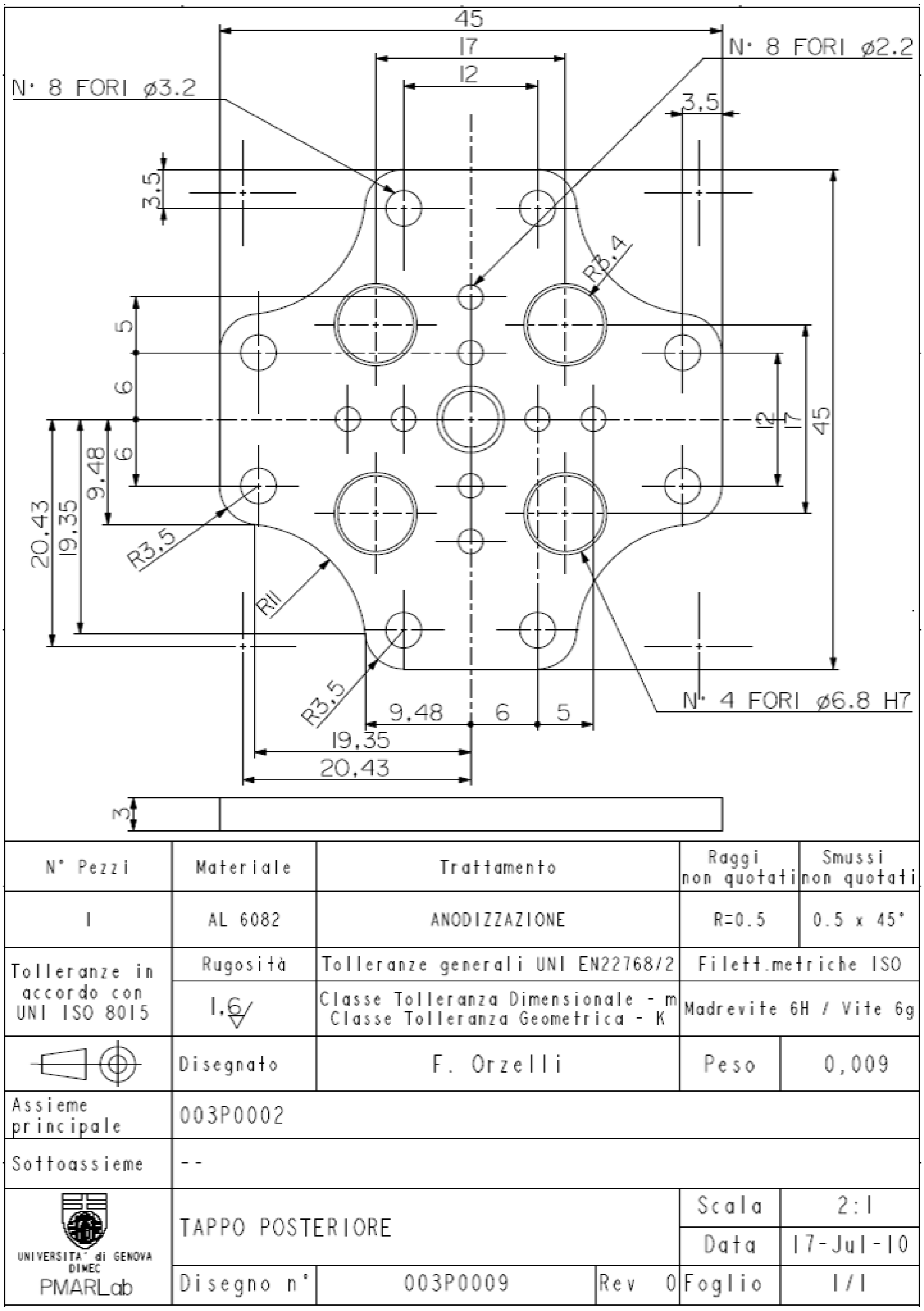


Front Flange Design (003P0004)



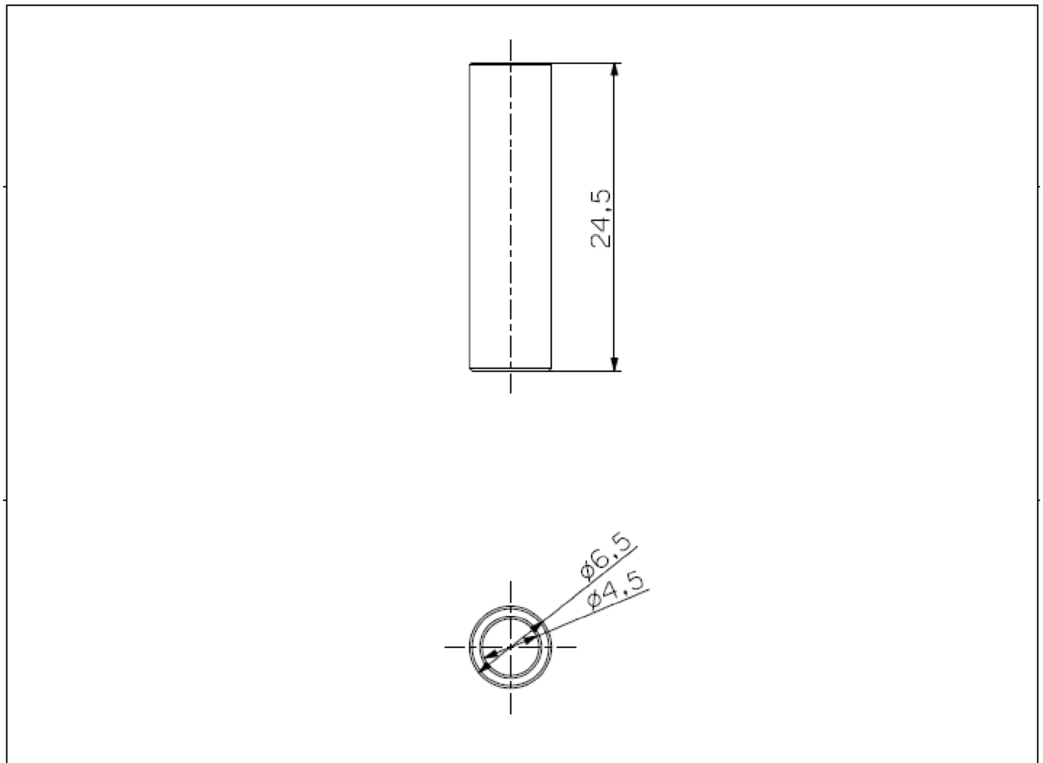
N° Pezzi	Materiale	Trattamento		Raggi non quotati	Smussi non quotati
1	TEFLON	--		R=0.3	0.5 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2		Filett.metriche ISO	
	1,6	Classe Tolleranza Dimensionale - f Classe Tolleranza Geometrica - K		Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli		Peso	0,003
Assieme principale	003A0002				
Sottoassieme	--				
UNIVERSITA' di GENOVA DIMEC PMARLab	TAPPO			Scala	2:1
				Data	17-Jul-10
	Disegno n°	003P0004	Rev 0	Foglio	1/1

Rear Flange Design (003P0009)



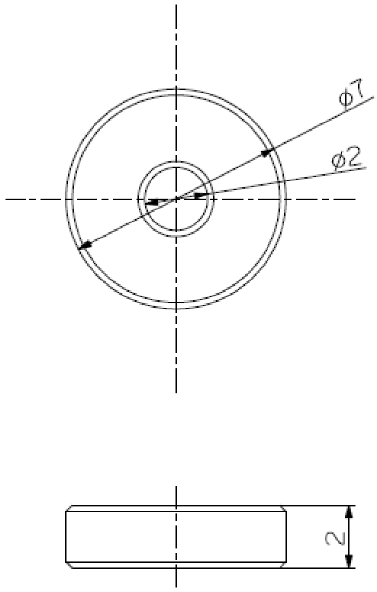
D Assembly Procedure Components Design

Spacer Design (003P0006)



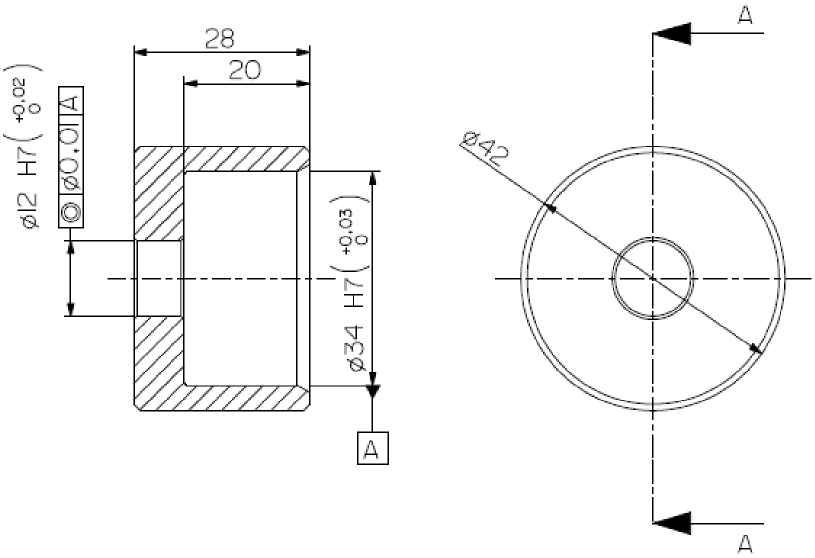
N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
4	AL 6060	ANODIZZAZIONE	R=0.5	0.5 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2	Filett.metriche ISO	
	1,6	Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	0,001
Assieme principale	003A0002			
Sottoassieme	--			
UNIVERSITA' di GENOVA DIMEC PMARLab	DISTANZIALE		Scala	2:1
			Data	18-Jul-10
	Disegno n°	003P0006	Rev 0	Foglio 1/1

Washer Design (003P0003)



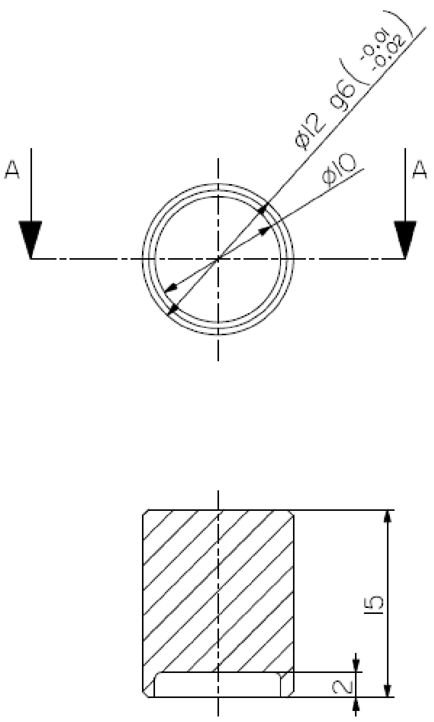
N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
4	Fe 360	--	R=0.2	0.2 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità 1,6	Tolleranze generali UNI EN22768/2 Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Filett.metriche ISO Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	0,000
Assieme principale	003A0002			
Sottoassieme	--			
UNIVERSITA' di GENOVA DIMEC PMARLab	RONDELLA		Scala	5:1
			Data	18-Jul-10
	Disegno n°	003P0003 Rev 0	Foglio	1/1

Zero gauge Design (003P0011)



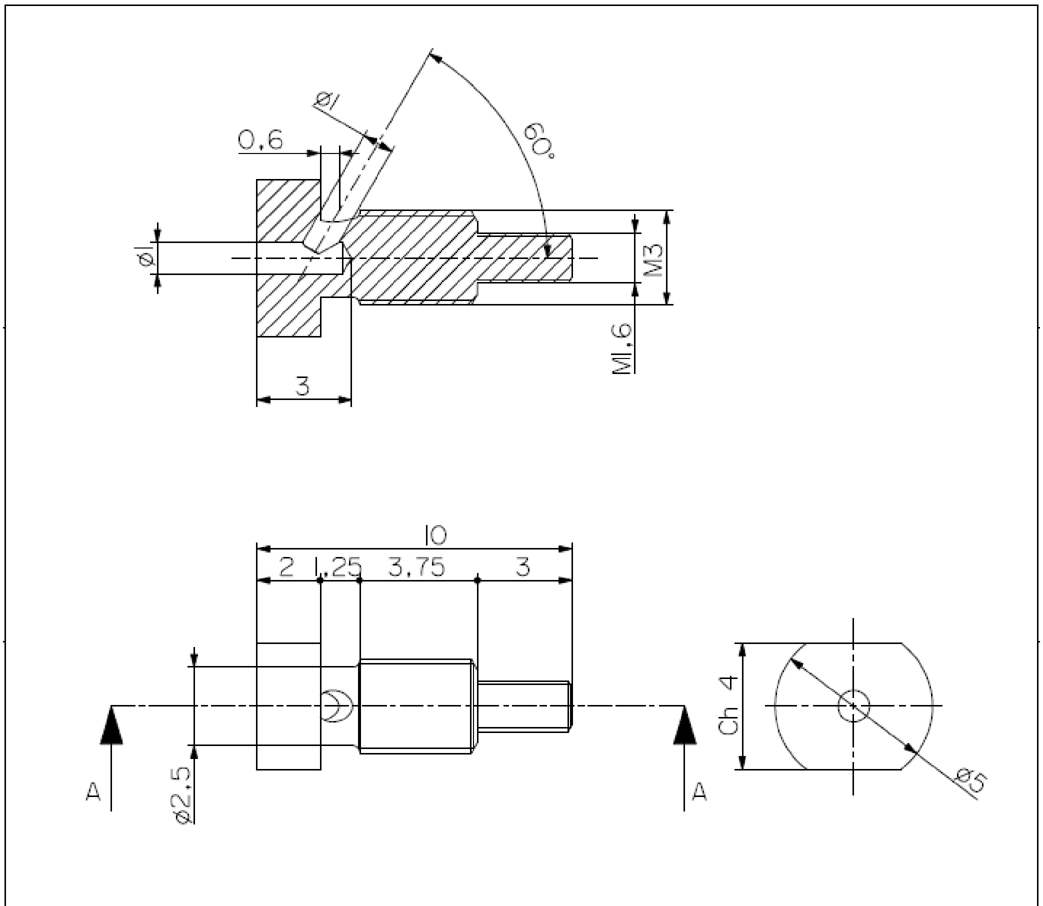
N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
1	AISI 304	--	R=0.5	0.5 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2	Filett.metriche ISO	
	1.6	Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	0,157
Assieme principale	003A0002			
Sottoassieme	--			
UNIVERSITA' di GENOVA DIMEC PMARLab	CALIBRO ZERO		Scala	1:1
			Data	18-Jul-10
	Disegno n°	003P0011 Rev 0	Foglio	1/1

Pivot gauge Design (003P0012)



N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
1	AL 6060	ANODIZZAZIONE	R=0.5	0.5 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità	Tolleranze generali UNI EN22768/2	Filett.metriche ISO	
	1.6	Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	1530217,50
Assieme principale	003A0002			
Sottoassieme	- -			
UNIVERSITA' di GENOVA DIMEC PMARLab	PERNO CALIBRO		Scala	2:1
			Data	18-Jul-10
	Disegno n°	003P0012 Rev 0	Foglio	1/1

Tendon clamp Design (003P0008)



N° Pezzi	Materiale	Trattamento	Raggi non quotati	Smussi non quotati
4	AISI 304	--	R=0.5	0.5 x 45°
Tolleranze in accordo con UNI ISO 8015	Rugosità 1,6	Tolleranze generali UNI EN22768/2 Classe Tolleranza Dimensionale - m Classe Tolleranza Geometrica - K	Filett.metriche ISO Madrevite 6H / Vite 6g	
	Disegnato	F. Orzelli	Peso	0,001
Assieme principale	003A0002			
Sottoassieme	--			
UNIVERSITA' di GENOVA DIMEC PMARLab	MORSA TENDINE		Scala / Data	5:1 / 18-Jul-10
	Disegno n°	003P0008	Rev 0 / Foglio	1/1

E Linear motor LM0830-040-01 Data Sheet

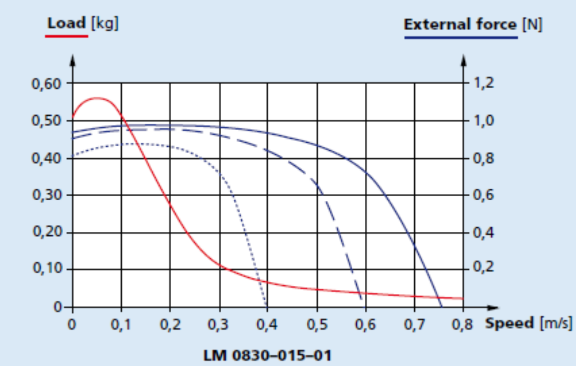
Series LM 0830 ... 01

		LM 0830–		015–01	040–01	
1	Continuous force [1]	$F_{e\,max.}$	1,03			N
2	Peak force [1] [2]	$F_{p\,max.}$	2,74			N
3	Continuous current [1]	$I_{e\,max.}$	0,53			A
4	Peak current [1] [2]	$I_{p\,max.}$	1,41			A
5	Back-EMF constant	k_E	1,58			V/m/s
6	Force constant [3]	k_F	1,94			N/A
7	Terminal resistance, phase-phase	R	7,37			Ω
8	Terminal inductance, phase-phase	L	117			µH
9	Stroke length	$s_{max.}$		15	40	mm
10	Repeatability [4]			40	40	µm
11	Precision [4]			120	140	µm
12	Acceleration [5]	$a_{e\,max.}$		206,9	147,8	m/s²
13	Speed [5] [6]	$v_{e\,max.}$		1,8	2,4	m/s
14	Thermal resistance	R_{th1} / R_{th2}	6,6 / 37,4			K/W
15	Thermal time constant	τ_{w1} / τ_{w2}	4 / 291			s
16	Operating temperature range		– 20 ... +125			°C
17	Rod weight [7]	m_m		5	7	g
18	Total weight [7]	m_t		15	17	g
19	Magnetic pitch	τ_m	12			mm
20	Rod bearings		polymer sleeves			
21	Housing material		metal, non-magnetic			
22	Direction of movement		electronically reversible			

[1] thermal resistance R_{th2} by 55% reduced
[2] for max. 1 second with a duty cycle of 10%
[3] with sine wave commutation
[4] typical values with integrated linear Hall sensors and Motion Controller MCLM 3003/06 S/C.
The values depend on conditions of use
[5] theorical value, referring only to the motor
[6] with a triangular speed profile and the max. stroke
[7] rounded value, for reference only

Notes: These motors are for operation with DC-voltage < 50 V DC.
The given values are for free standing motors.
The mounting with magnetic conductive metal can influence the characteristics of the motor.

Caution: Presence of strong magnetic fields. Static sensitive device.



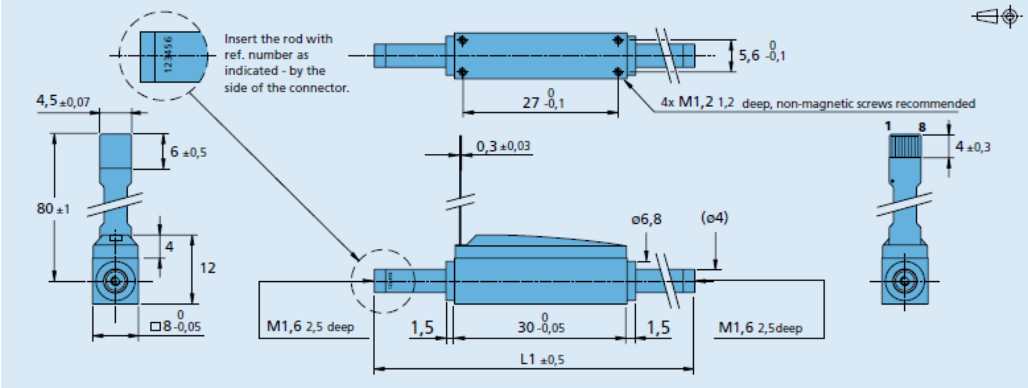
Trapezoidal motion profile (t1 = t2 = t3)

Displacement distance:	15 mm
Friction coefficient:	0,2
Slope angle:	0°
Rest time:	0,1 s

Load: The max. permissible load at a given speed with an external force of 0 N

External force: The max. permissible external force at a given speed with a load of:
- 0,035 Kg
- 0,05 Kg
- 0,1 Kg

Linear DC-Servomotor LM 0830



Ordering information

Linear DC-Servomotors Series	**Stroke** mm	**Rod length** L1 ±0,5 mm
LM 0830-015-01	−7,5 … +7,5	58
LM 0830-040-01	−20 … +20	82

Note: Single rod available on request.

Options

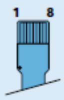
- Flexboard adapter (part no. L08.90.02), size 18 x 23 x 6 mm
- Cable with connector (part no. L12.09.01), 200 mm length ± 10 mm, 8 conductors

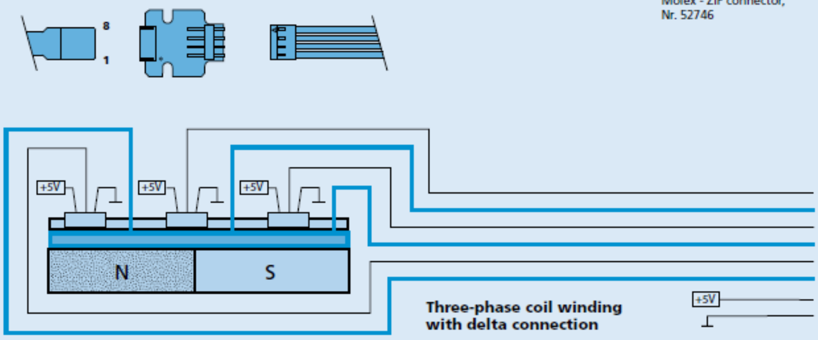
Cable and connection information

Motor flexboard | **Flexboard adapter** | **Cable for connection with Motion Controller**

Recommended connector
Molex - ZIF connector, Nr. 52746

Flexboard
8 circuits; 0,5mm pitch





Connection

No.	Function
6	Hall sensor C
1	Phase C
7	Hall sensor B
2	Phase B
8	Hall sensor A
3	Phase A
5	Logic supply +5V
4	Logic GND

F Motion Controller MCLM3003-06C Data Sheet

Series MCLM 3003/06 C

		MCLM 3003 C	MCLM 3006 C	
Power supply	U_B	12 ... 30	12 ... 30	V DC
PWM switching frequency	f_{PWM}	78,12	78,12	kHz
Efficiency	η	95	95	%
Max. continuous output current [1]	I_{dauer}	3	6	A
Max. peak output current	I_{max}	10	10	A
Total standby current	I_{el}	0,06	0,06	A
Speed range [2]		2 ... 10 000	2 ... 10 000	mm/s
Scanning rate	N	100	100	µs
Encoder resolution with Hall Sensors [3]		≤ 3 000	≤ 3 000	inc./τ_m
Resolution with external encoder [3]		≤ 65 535	≤ 65 535	inc./mm
Input/output (partially free configurable)		3	3	
Operating temperature range		0 ... + 70	0 ... + 70	°C
Storage temperature		– 25... + 85	– 25 ... + 85	°C
Housing material		without housing	zinc, black coated	
Weight		18	160	g

[1] at 22°C ambient temperature
[2] Speed in the range 1 ... 5 mm/s may have fluctuations due to the motor type, load characteristics and controller parameters
[3] τ_m is the magnetic pitch of the linear motor

Connection information				
Connection "CANH", "CANL":			CAN-High / CAN-Low	
Interface			CAN	
Communication protocol			CANopen	
Max. transfer speed rate			1	Mbit/s
Connection "AGND":				
– analog ground			analog GND	
– digital input	external encoder		channel B	
		R_{In}	10	kΩ
		f	≤ 400	kHz
Connection "Fault":				
– digital input		R_{In}	100	kΩ
– digital output (open collector)		U	≤ U_B	V
		I	≤ 30	mA
		clear	switched to GND	
		set	high-impedance	
	fault output	no error	switched to GND	
		error	high-impedance	
	signal output	f	≤ 2	kHz
		resolution	1...255	inc./τ_m
Connection "AnIn":			"AGND" as GND	
– analog input	set position value	U_{In}	± 10	V
– digital input	external encoder		channel A	
		f	≤ 400	kHz
	step frequency input	f	≤ 400	kHz
		R_{In}	5	kΩ
Connection "+24V":		U_B	12 ... 30	V DC
Connection "GND":			ground	
Connection "3. In":				
– digital input		R_{In}	22	kΩ
– electronic supply voltage [4]		U_B	12 ... 30	V DC

[4] Optional on request

Connection information				
Phase connection "A", "B", "C":				
A		Phase A	brown [1]	
B		Phase B	orange [1]	
C		Phase C	yellow [1]	
	U_{out}	0 … U_B		V
PWM switching frequency	f_{PWM}	78,12		kHz
Hall Sensor connection "A", "B", "C":				
A		Hall Sensor A	green [1]	
B		Hall Sensor B	blue [1]	
C		Hall Sensor C	grey [1]	
	U_{In}	≤ 5		V
Connection "SGND":				
Signal GND		Signal ground	black [1]	
Connection "+5V":				
Output voltage for external use [2]	U_{out}	5	red [1]	V DC
Load current	I_{out}	≤ 60		mA

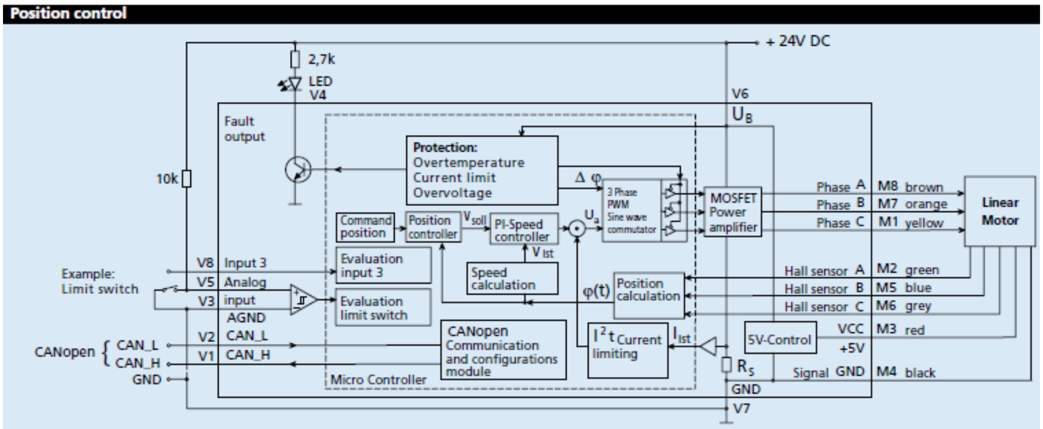
[1] Colour identification for linear DC-Servomotor
[2] E.g. Hall sensor

D-SUB-connector information			
Connection D-SUB-connector:			
Pin 2	CAN_L		CAN-Low
Pin 3	GND		Ground
Pin 7	CAN_H		CAN-High

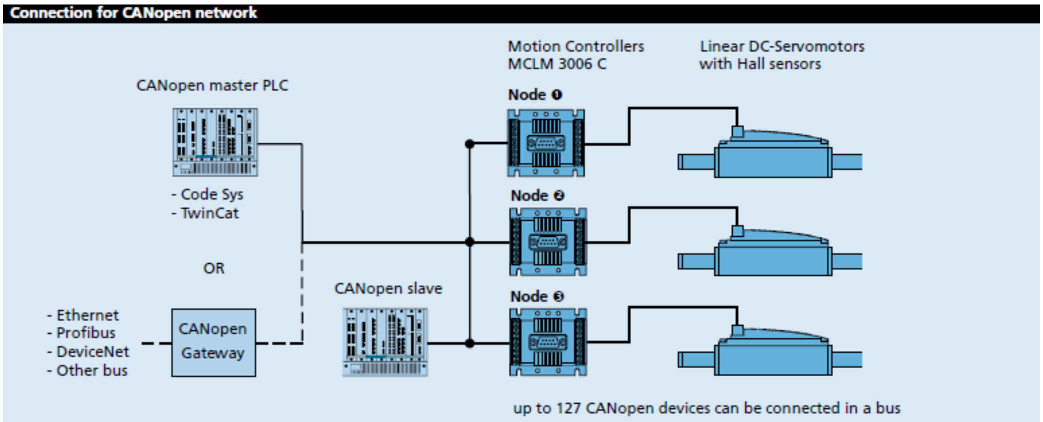
Digital inputs general information			
- PLC, default	high	12,5 … U_B	V
	low	0 … 7	V
- TTL	high	3,5 … U_B	V
	low	0 … 0,5	V

The signal level (PLC or TTL) of the digital inputs can be set over the interface (see instruction manual).

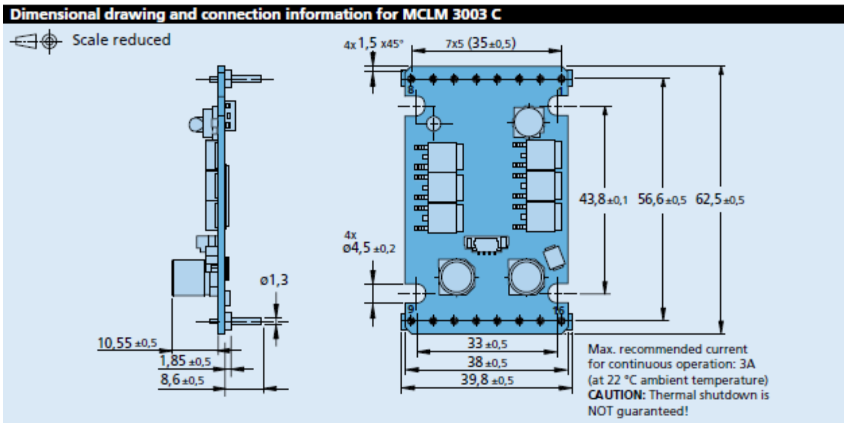
Position control



Connection for CANopen network



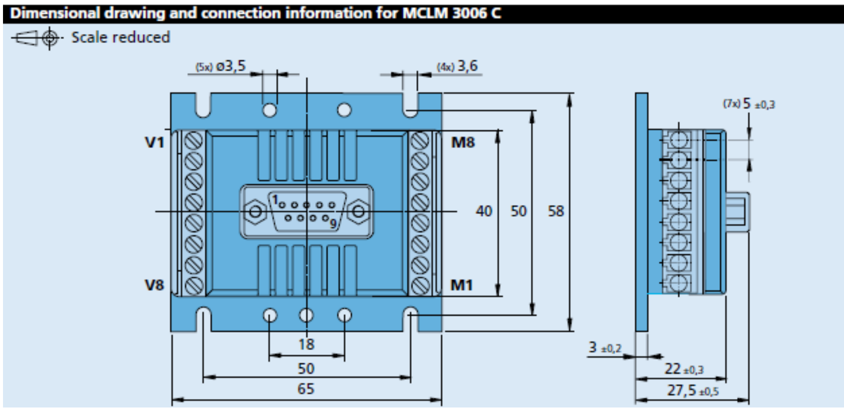
Dimensional drawing and connection information for MCLM 3003 C



Connection

Pin	Function
1	Ph C
2	Hall A
3	+ 5V
4	SGND
5	Hall B
6	Hall C
7	Ph B
8	Ph A
9	CAN_H
10	CAN_L
11	AGND
12	Fault
13	AnIn
14	+ 24V
15	GND
16	3. In

Dimensional drawing and connection information for MCLM 3006 C



Motor connection

No.	Function
M1	Ph C
M2	Hall A
M3	+ 5V
M4	SGND
M5	Hall B
M6	Hall C
M7	Ph B
M8	Ph A

Supply connection

No.	Function
V1	CAN_H
V2	CAN_L
V3	AGND
V4	Fault
V5	AnIn
V6	+ 24V
V7	GND
V8	3. In

G Microcamera MU9PC-MH

Specification

Mechanical

Description	Symbol	Value	Units
Height	H	8.5	mm
Width	W	15.0	mm
Depth	D	15.0	mm
Weight	M	4.0	g
Housing material and technology		Machined Aluminum alloy, black anodized	
Lens adapter, material and technology		M12x0.5 thread, machined Aluminum alloy, anodized to black color	

Sensors

Description	MU9PC	MU9PM	Units
Brand	MT9P031I12STC	MT9P031I12STM	
Micron Datasheet	Rev. C 9/07 EN	?????	
Type	Rolling shutter, Global Reset Release		
Pixel resolution (H × V)	2592 × 1944		pixels
Chip size (H × V)	5.70 x 4.28		mm
Unit cell size (H × V)	2.2 x 2.2		µm
Color filter	RGB Bayer mosaic	None	
FWC (*), typical	TBD		ē
Dark current (**), typical	TBD		ē/p/s

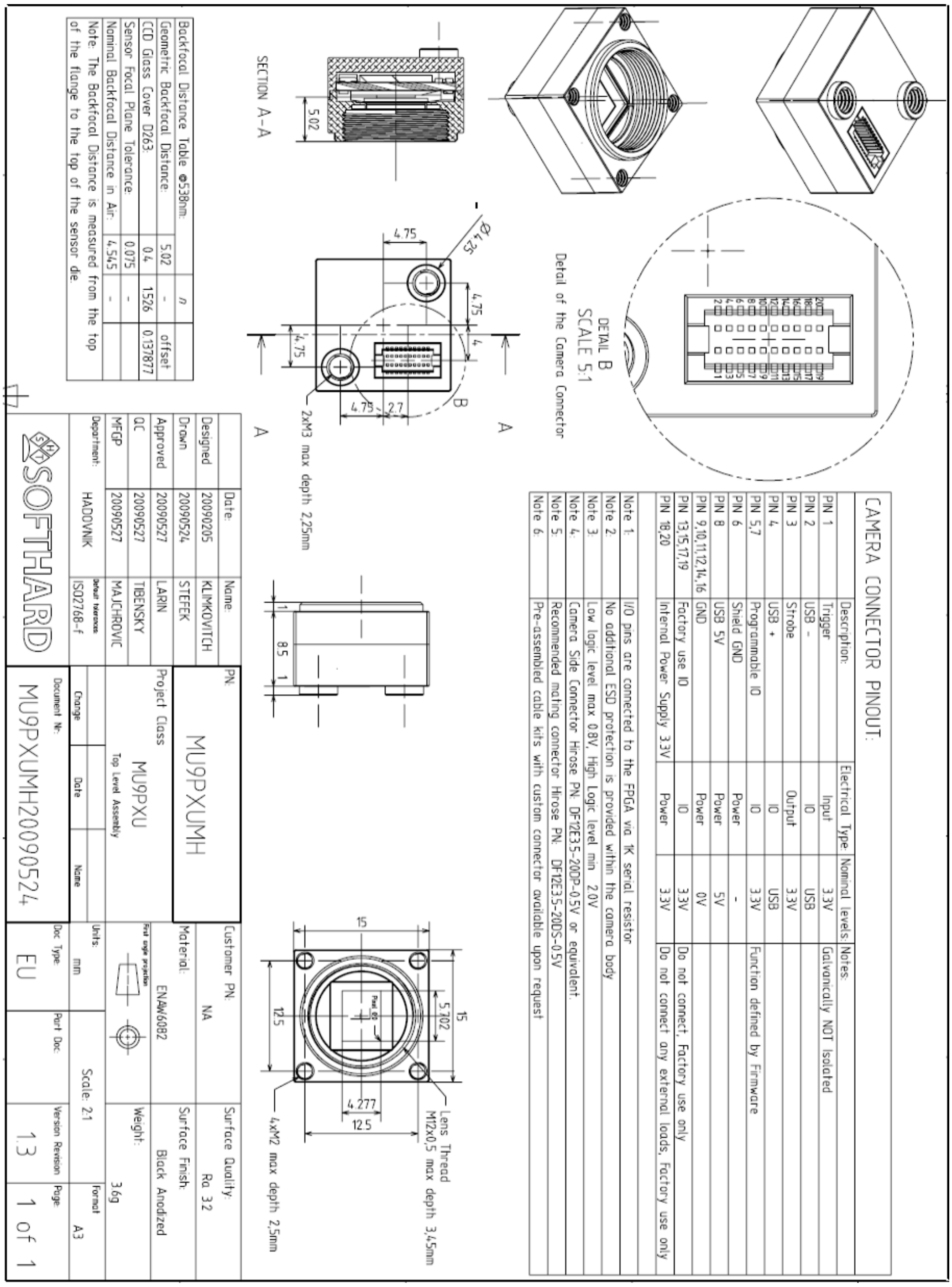
Camera core

Description	Symbol	Value	Units
Digitization		12	Bit
Supported bit resolutions		8, 10, 12	Bit/pix
Exposure time	EXP	20µs ... 500sec	
Variable Gain Range	VGA	18	dB
Refresh rate	MRR	8 TBD	Fps
Trigger/sync input (r)		Asynchronous CMOS 3.3V	
Trigger/sync output (rr)		CMOS 3.3V	
Pixel Dynamic range, Typical	DR	~70	dB
SNR, max	SNR	~38	dB
Linearity (*)	Lin	<1	%
Responsivity @550nm	R	1.4	V/lux-sec
External interface		USB 2.0	

Supported readout modes

Mode	Binning/ Skipping	Mode MU9PC	Mode MU9PM	Pixels	Frm/s	Bit/pix
0	1x1	Color	B/W	2592×1944	5.8	12
1	2x2 bin	Color	B/W	1296×972	17	12
2	4x4 bin	Color	B/W	648×486	36	12
3	2x2 skip	Color	B/W	1296×972	22	12
4	4x4 skip	Color	B/W	648×486	83	12
5	6x6 skip	Color	B/W	430×324	163	12
6	7x7 skip	Color	B/W	368×276	200	12

Camera Design



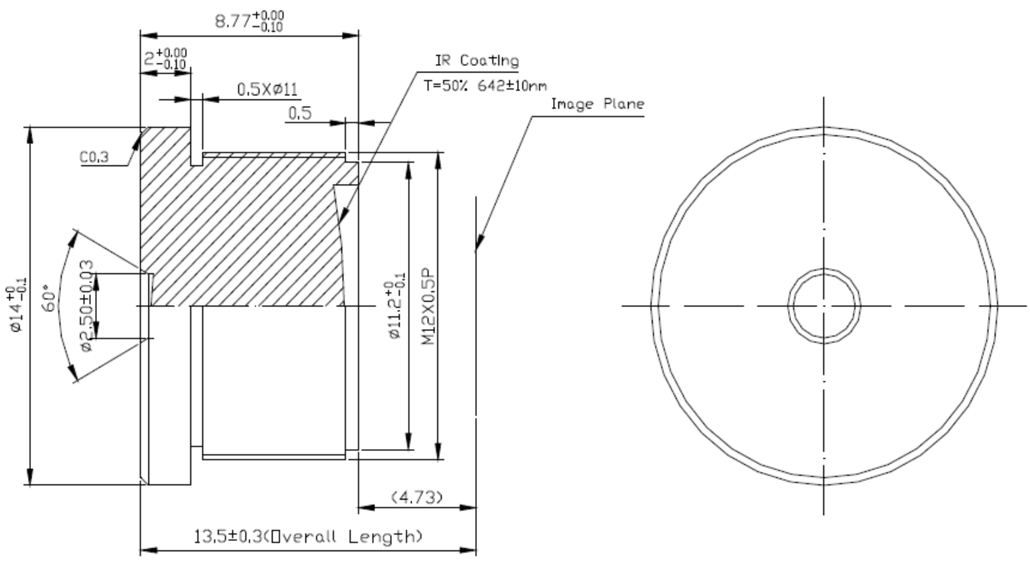
H Lens S-Mount DSL853

Specification

Optical specifications

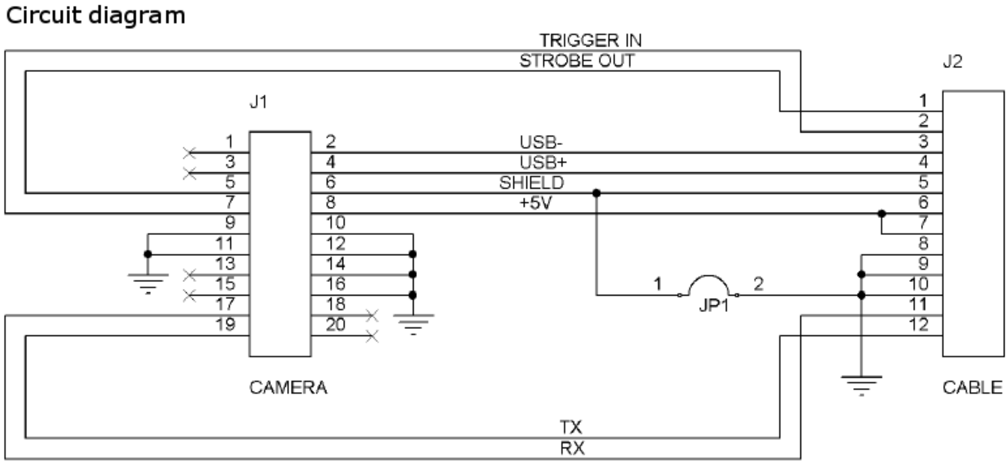
PN	DSL853
Description	Low-profile DSC lens
Imager Format	1/2"
Imager Resolution	Up to 2.1M
Focal length (mm)	8.0
F/#	3.2
Max. Image Circle(mm)	8.6
Diagonal Field of View (deg)	56.2
35mm Equivalent Focal Length (mm)	43
Modulation Transfer Function (MTF)	See MTF data for details
Resolution	See MTF data for details
Distortion	-1.58%
Corner chief ray angle (deg)	13.54
Relative Illumination	62%
Total optical path length (mm)	12.9
Mechanical	See below
Filter Option	IR-cut coating included
Lens mount option	Optional

Lens Design

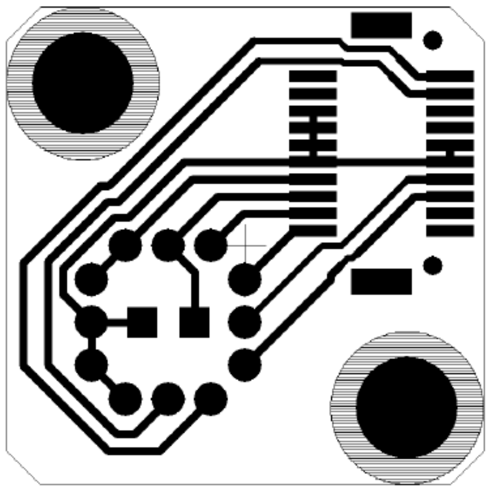


I PCB Board (AGC501P1)

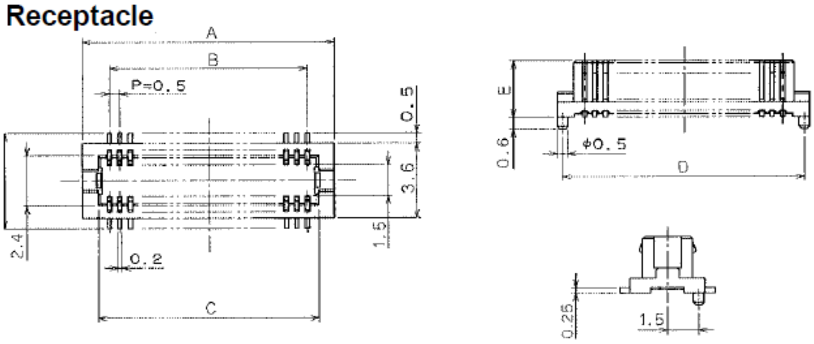
Circuit diagram



Circuit layout



Receptacle



Part Number	CL No.	Number of Contacts	A	B	C	D	E	F
DF12-20DS-0.5V (**)	537-0003-6- **	20	7.1	4.5	5.6	6.6		8.0

J Miniature cables (STC-36T-12))

Multicore Cables, shielded

Teflon® PFA insulation. Shield and conductors made of silver plated copper. Respectively the STNCC series made from nickel plated copper. Continuous operating temperature for STC-series -190°C to +200°C. STNCC-series -190°C to +250°C. Conductors are twisted. For a specification on the conductors refer to "Insulated wires" below.

Designation	No. of cores	Outer Diameter mm	AWG	Rated Voltage VAC	Test Voltage VAC
STNCC-38T-4	4	1.08 ±0.15	38	100	1300
STNCC-38T-6	6	1.27 ±0.15	38	100	1300
STC-36T-2	2	1.03 ±0.15	36	150	1300
STC-36T-3	3	1.08 ±0.15	36	150	1300
STC-36T-4	4	1.15 ±0.15	36	150	1300
STC-36T-6	6	1.36 ±0.15	36	150	1300
STC-36T-7	7	1.37 ±0.15	36	150	1300
STC-36T-12	12	1.77 ±0.15	36	150	1300
STC-32T-2	2	1.42 ±0.15	32	250	1500
STC-32T-3	3	1.50 ±0.15	32	250	1500
STC-32T-4	4	1.62 ±0.15	32	250	1500
STC-32T-6	6	1.90 ±0.15	32	250	1500
STC-32T-7	7	1.92 ±0.15	32	250	1500
STC-32T-12	12	2.53 ±0.15	32	250	1500

Jacket color is white except STNCC the jacket is gray. Other jacket colors are available on request. Designations marked in the table with gray background are typically available from stock. All other designations and custom cables with any number of cores can be supplied at minimum order of 250 meters.

Insulated Wires

Teflon® PFA insulation. Conductors are made off silver plated copper, respectively the STNCC series made from nickel plated copper. Continuous operating temperature for SDC and STC-series -190°C to +200°C. STNCC-series is -190°C to +250°C.

Designation			CONDUCTOR SPECIFICATION							INSULATION	
	Outer Diameter mm	Continuous operating temperature °C	Cross Section mm^2	Compo-sition mm	Dia-meter mm	Compo-sition	AWG	Resis tance Ω / m	Tensile Strength N	Rated Voltage VAC	Test Voltage VAC
STNCC-38T-1x	0.27 ±0.025	-190 .. +250	0.009	7 x 0.040	0.13	CuNi	38	2.2	>2.2	100	1200
STC-36T-1x	0.30 ±0.025	-190 .. +200	0.014	7 x 0.050	0.15	CuAg	36	1.4	>3	150	1300
SDC-34T-1x	0.30 ±0.025	-190 .. +200	0.018	1 x 0.15	0.15	CuAg	34	1.0	>4	150	1300
STC-34T-1x	0.36 ±0.030	-190 .. +200	0.022	7 x 0.063	0.19	CuAg	34	1.0	>4	150	1300
STC-32T-1x	0.49 ±0.035	-190 .. +200	0.037	19 x 0.05	0.24	CuAg	32	0.5	>8	250	1500
SDC-32T-1x	0.36 ±0.030	-190 .. +200	0.032	1 x 0.203	0.20	CuAg	32	0.6	>7	150	1300