ISTITUTO ITALIANO DI TECNOLOGIA
ROBOTICS, BRAIN AND COGNITIVE SCIENCES

Upgrading iCub Shoulder Motors

A proposal for collaboration between IIT-RBCS and Phase S.r.l.

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Goal of the study

The goal of this study is to investigate the possibility to upgrade the high power motor groups (which employ Kollmorgen-DanaherMotion RBE brushless motors [1]) on the upper-body of the RobotCub[1] platform. The alternative motors from Phase [2] are meant to outperform the ones currently used in terms of nominal torque, peak torque and power density.

To allow a seamless integration on the iCub robotic platform detailed dimensions for the motor stator housings and rotor shafts have been included in the present document.

Motor assemblies

The shoulder system comprises a complex and very compact 3DOF joint based on a differential pulley system. This joint is actuated by three motor groups which are shown in Fig.1.

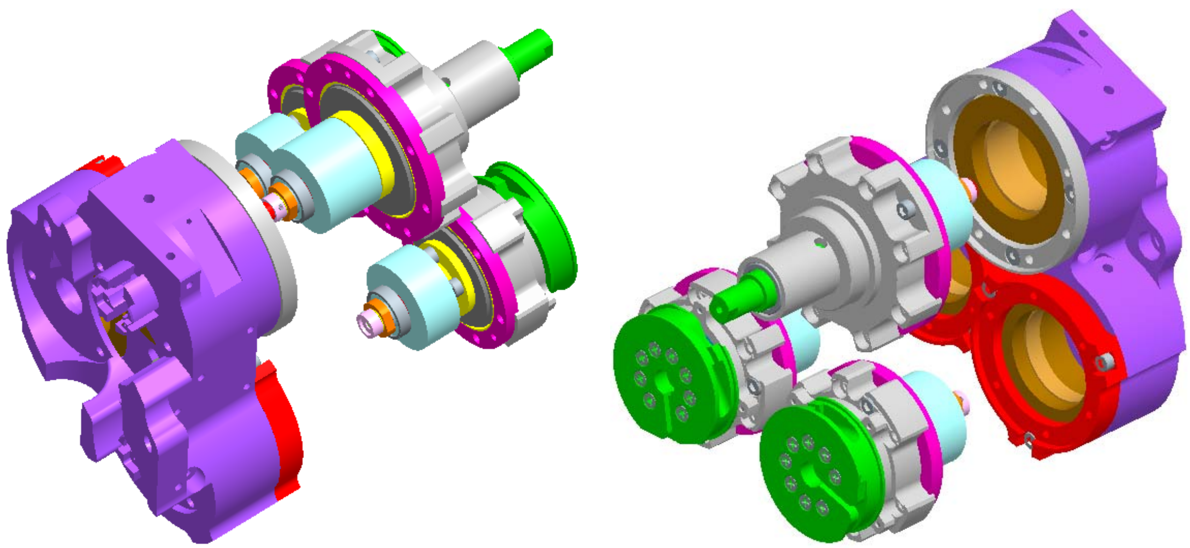
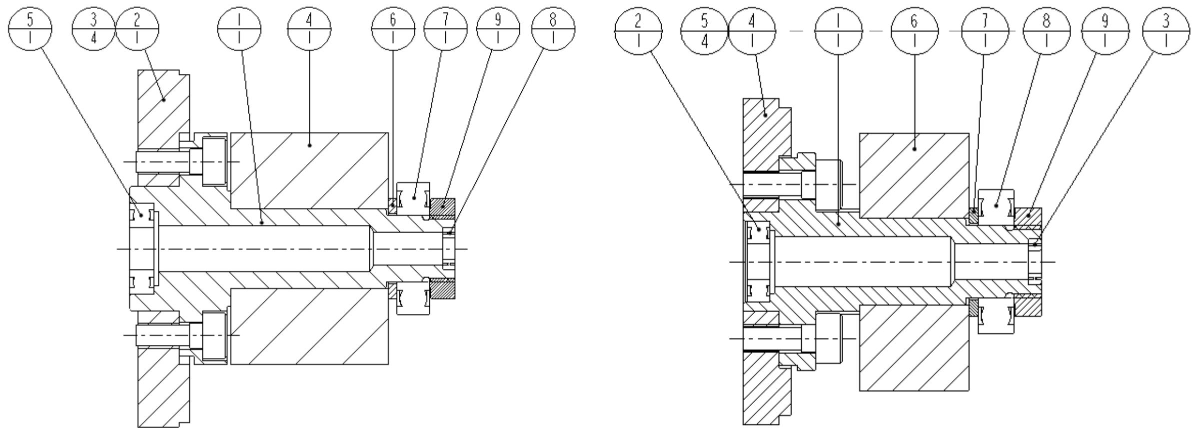


Fig.1: Right shoulder motor groups

The motor stators are housed in a compact and light-weight aluminium frame. This sub-assembly will be referred to with its RobotCub code: RC_TLR_003_G_014. The motor groups are similar since they both comprise a Kollmorgen-DanaherMotion RBE 012 brushless frameless motor and a CSD frameless Harmonic Drive [3]. However the topmost one is slightly bigger since a RBE 01211 motor and a CSD-17-100-2A Harmonic Drive have been selected. The two other groups, which drive the roll-pitch-roll differential mechanism, incorporate smaller RBE 01210 motors and CSD-17-100-2A Harmonic Drives.

At the kernel of these sub-assemblies are the stator-wave-generator groups which will be referred to with their codes: RC_TLR_003_G_004 and RC_TLR_003_G_009 for the big one and small ones a respectively. A diagrammatic view of the two sub-assemblies is show in Fig.2.

[1] Note: RobotCub is the EU-funded project code FP6-IST-04370; iCub is the humanoid robot developed as part of the RobotCub project.



RC_TLR_003_G_004 RC_TLR_003_G_009

Fig.2: Rotor group sub-assemblies.

Torque requirements

The torque requirements for the iCub robot have been determined with a virtual simulation: the torques generated by the shoulder must allow a small sized humanoid robot sustain a continuous 0.5Hz crawling motion [4,5,6,7]. This procedure yielded the current torque specification for the shoulder joints which is of 40Nm.

More recent tests on the iCub prototype have however demonstrated that while performing reaching movements at high angular velocities joint torques rarely exceed the value of 8Nm.

Other limits on the maximum torques that can be exerted are posed by the tendon crimping resistance (which has not been evaluated so far), and by HarmonicDrive maximum impulsive loading [3].

Given these design specifications two possible alternatives can be devised.

1. A first more conservative upgrade would just be to substitute the current motors with better performing ones.
2. A second option would be to substitute both the brushless motors and the HarmonicDrive speed reducers. If the enhanced torque capabilities will be sufficient one could consider a slight relaxation of the design specifications. Lower requirements in terms of maximum torque would allow the use of speed reducers with lower gear ratios. CSD-17-50-2A and CSD-14-50-2A Harmonic Drive reducers could be seamlessly integrated in the current design thus reducing the unwanted effects of frictional phenomena and enhancing the overall arm back-driveability.

Electrical parameters

As soon as the design has reached a sufficient stage of completion, a tentative set of parameters should be provided to aim the redesign of a suitable electronic drive and sensor. Here is a list of the minimum set of parameter of interest:

- number of poles: *Np*
- maximum mechanical speed: *ωmax[rpm]*
- Phase to phase resistance: *Rpp [mΩ]*
- Phase to phase inductance: *Lpp [mH]*
- Nominal current: *In [Arms]*
- Peak current (specify conditions: sustainable time, temperature rise…): *Ip [Arms]*
- Demagnetization current: *Id [A]*
- Torque constant: *Kt [Nm/Arms]*
- Back emf: *Bemf [V/krpm]*
- Maximum continuous power (S0 class, continuous). *Pmax[W]*
- Peak power (Sx class, specify conditions: sustainable time, temperature rise…): *Pp [W]*
- Maximum operational temperature. *Tmax[°C]*
- Thermal impedance: *Rth [°C/W]*

Each parameter should include an indication of the possible estimation variance with respect to the final product.

If possible to determine at design stage, some useful some data would be those regarding:

- Efficency (specify conditions, nominal and peak)
- Field weakening characteristics (Deflussabilità)
- Spectral distribution of Bemf
- Cogging torque
- Optimal sensor feedback and control strategies

RBE 012 motor data

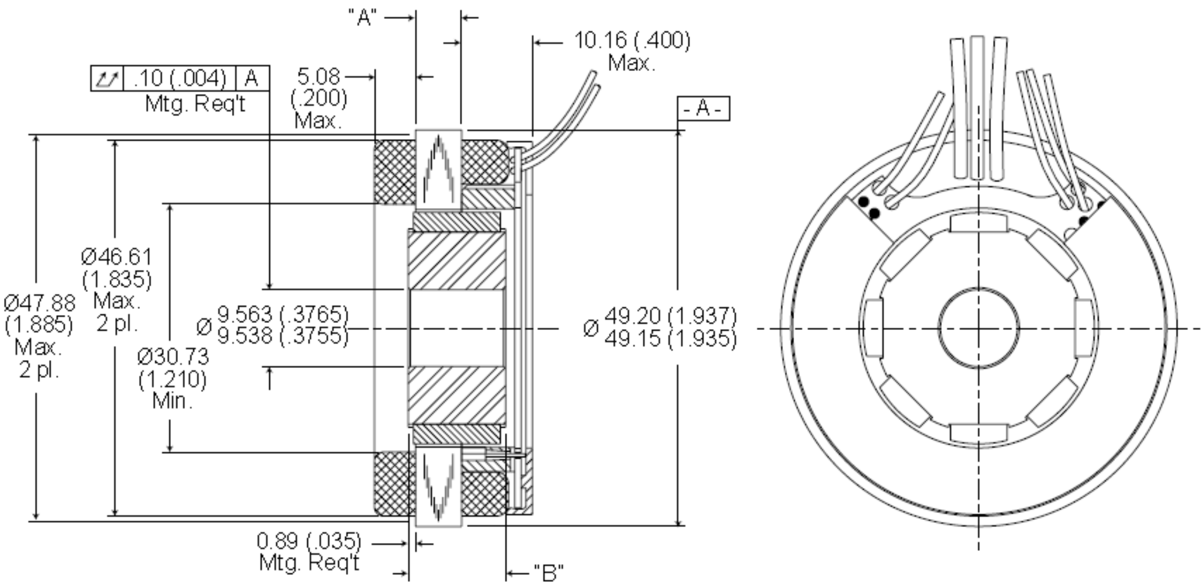
In the following section the catalogue data for the RBE 0121X motors are reported.

Model	**Units**	**1210**			**1212**		
Dimensions							
		nominal value	tolerance		nominal value	tolerance	
stator outer diameter	[mm]	49.175	±0.005		49.175	±0.005	
stator outer diameter (approx.)	[mm]	30.730			30.730		
rotor inner diametre	[mm]	9.538	±0.0125		9.538	±0.0125	
stator length	[mm]	20.96			27.94		
rotor length	[mm]	12.07			19.05		
Mechanical Data							
Max Cont. Output Power at 25°C amb.	[W]	106			152		
Max Mechanical Speed	[rpm]	18000			18000		
Continuous Stall Torque at 25°C amb.	[Nm]	0.12			0.22		
Peak Torque	[Nm]	0.342			0.806		
Max Torque for Linear KT	[Nm]	0.3420			0.8060		
Motor Constant	[Nm/sqrt(W)]	0.0280			0.0500		
Thermal Resistance*	[°C/Watt]	4.25			3.86		
Viscous Damping	[Nm/rpm]	9.18E-007			2.09E-006		
Max Static Friction	[Nm]	0.0120			0.0150		
Max Cogging Torque (Peak to Peak)	[Nm]	0.0029			0.0046		
Inertia	[kg*m^2]	5.15E-006			8.47E-006		
Weight	[kg]	0.1260			0.2030		
Number of Poles	[-]	8			8		
Electrical Data							
	winding type	**A**	**B**	**C**	**A**	**B**	**C**
Current at Cont. Torque	[A]	5.41	3.89	6.95	5.81	3.63	9.06
Current at Peak Torque	[A]	15	10.6	18.9	20	10.6	26.8
Torque Sensitivity	[Nm/A]	0.024	0.033	0.018	0.041	0.066	0.026
Back EMF constant	[V/krpm]	2.47	3.43	1.92	4.29	6.88	2.75
Motor Resistance	[Ohms]	0.698	1.380	0.431	0.664	1.750	0.276
Motor Inductance	[mH]	0.280	0.540	0.170	0.320	0.830	0.130

Dimensions

In the present section details of the motor dimensions and of the shaft and housing geometries and tolerances will be outlined. These data are also available in the ProE files attached to this report.

Motor dimensions



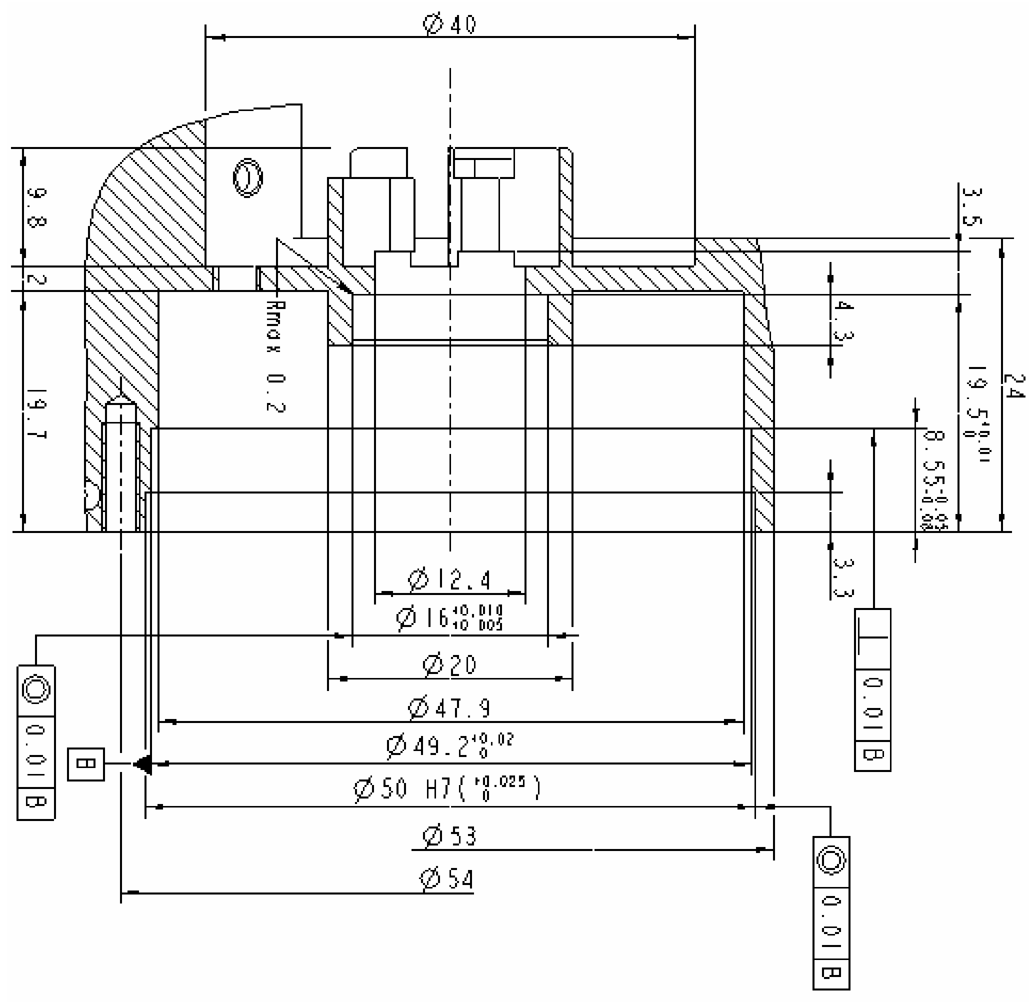
Notes:

1) Mounting surface is between Ø 47.88 (1.885) and Ø 49.17 (1.936) on both sides.

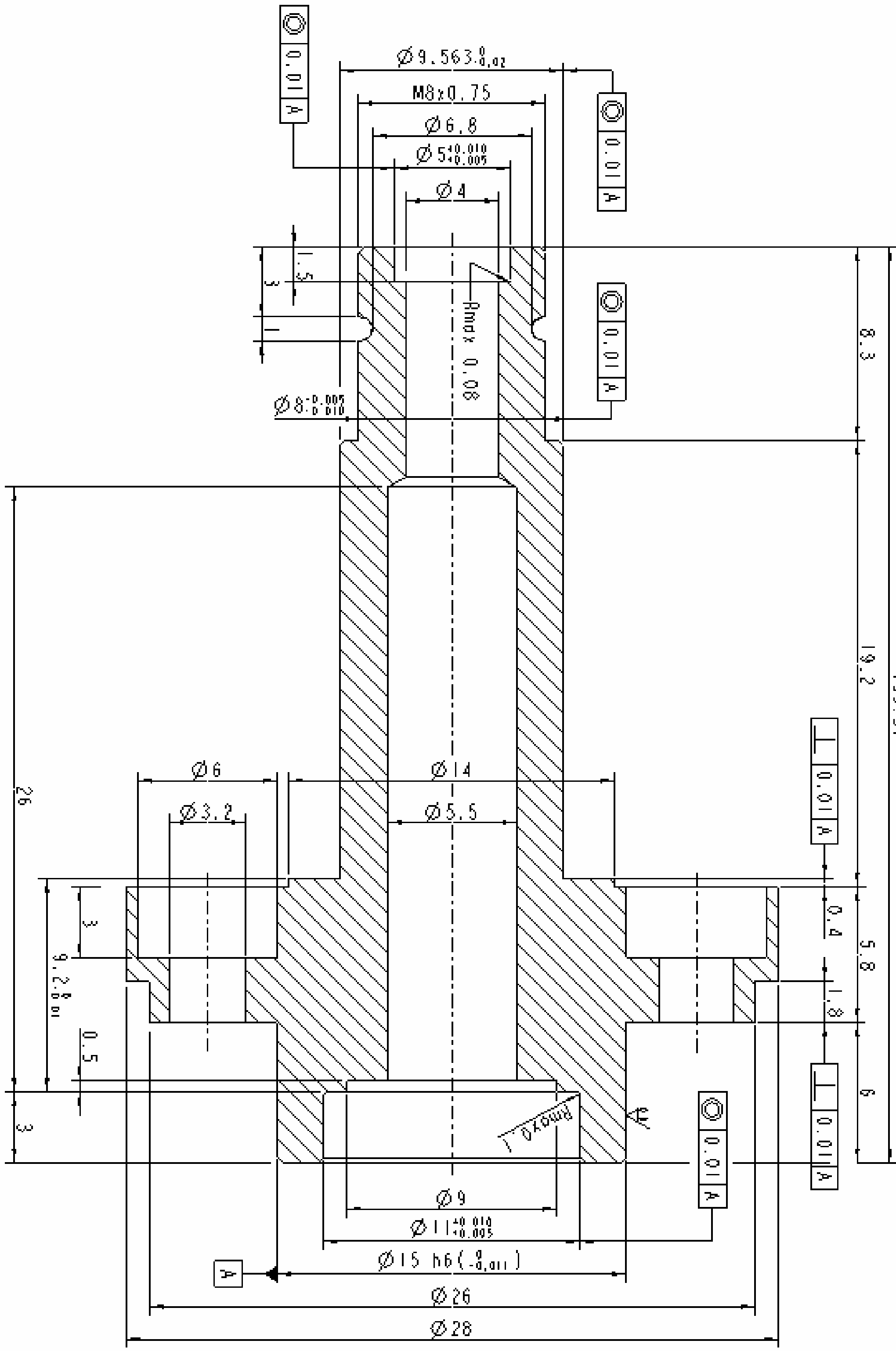
MODEL NUMBER	RBE-01210	RBE-01211
"A" Dimension	5.72 (0.225)	12.7 (0.500)
"B" Dimension	12.07 (0.475)	19.05 (0.750)
Tolerance ± .010 on "A" Dimension.		

Dimensions in mm (inches).
Product designed in inches.
Metric conversions provided for reference only.

RBE 01211

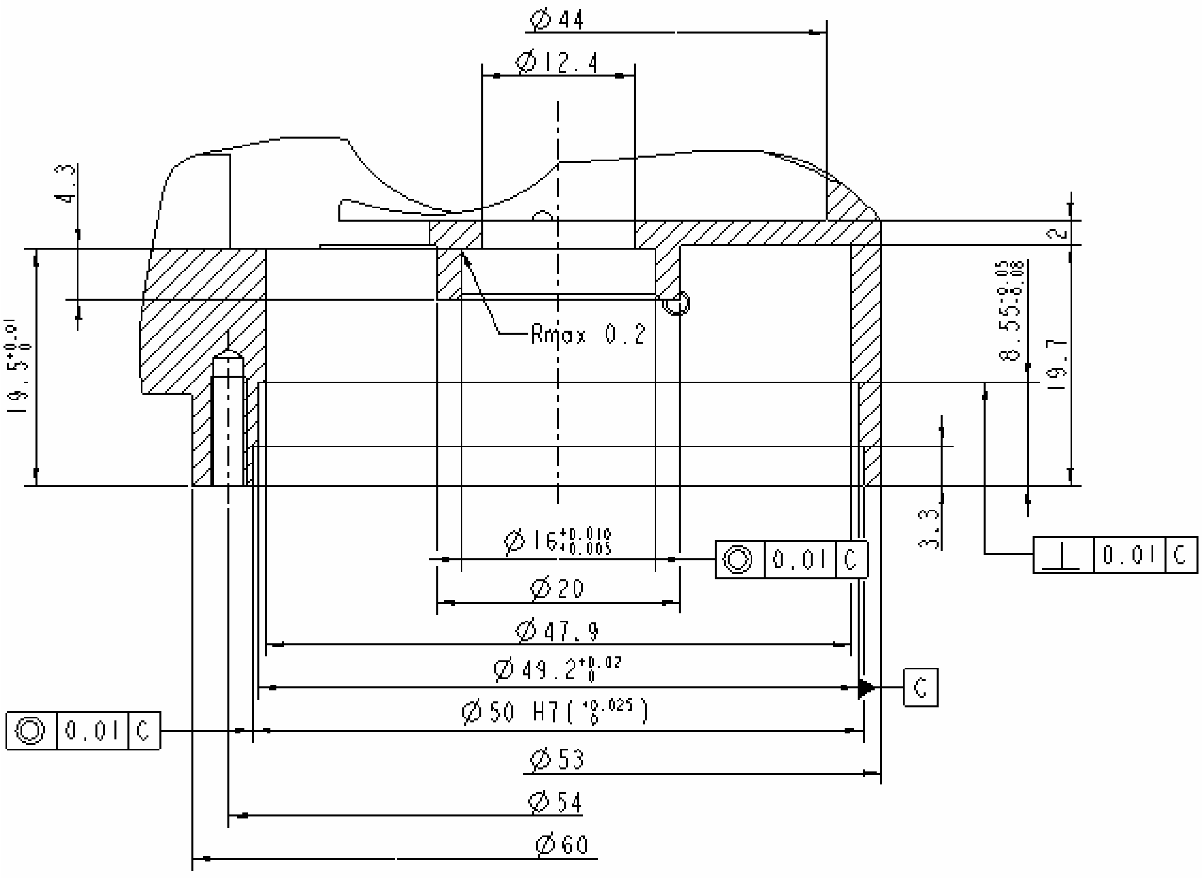


RBE 01211 stator housing

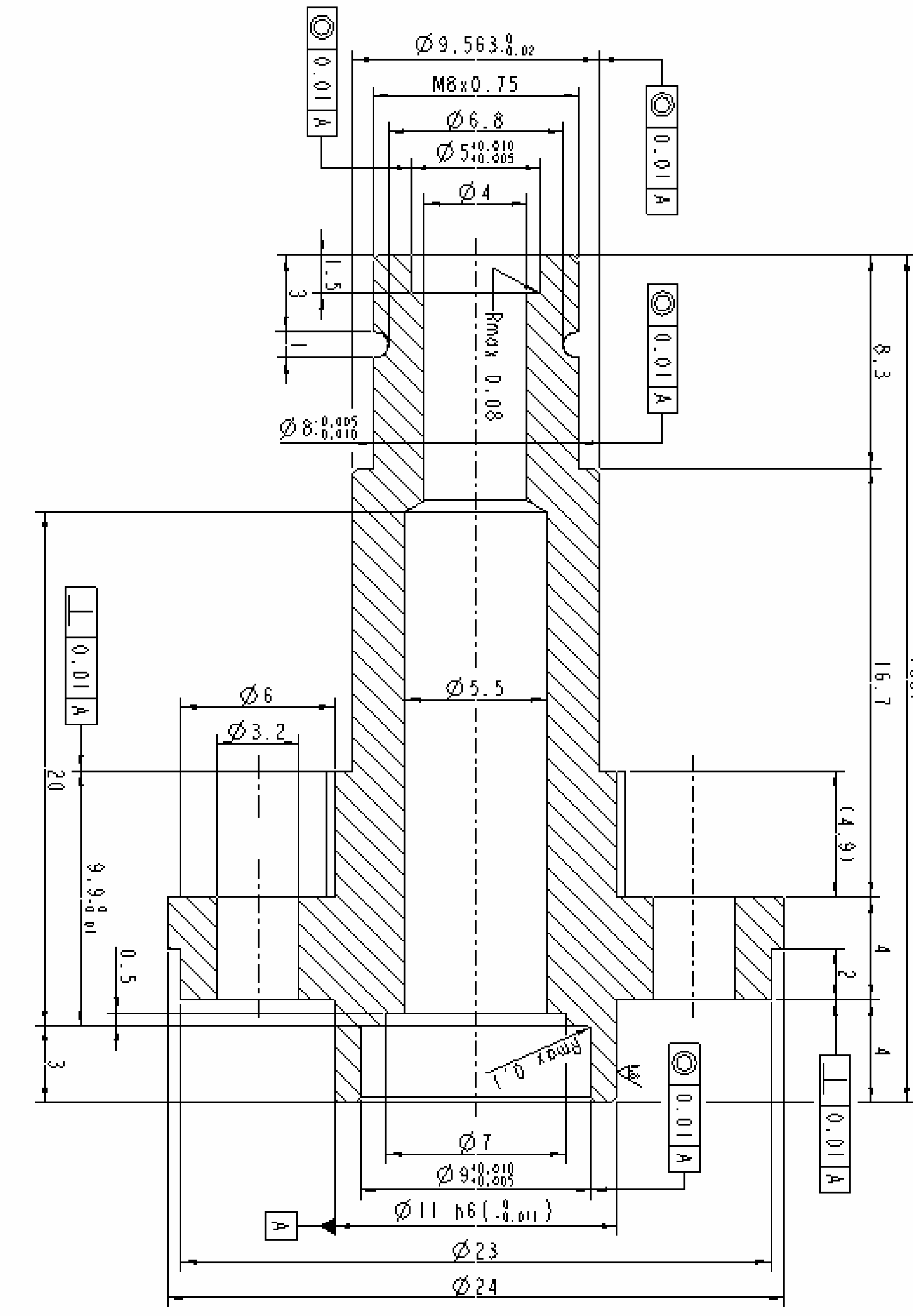


RBE 01211 rotor shaft

RBE 01210



RBE 01210 stator housing



RBE 01210 rotor shaft

References

[1] -. RBE(H) series motors datasheet. Kollmorgen DanaherMotion, 2003

[2] -. Phase website, http://www.phase.eu/

[3] -. CSD & SHD series datasheet (cup type component sets and housed units). Harmonic Drive Gearing 2008.

[4] G. Metta, D. Vernon, G. Sandini. D8.1 Initial specification of the iCub open system, 2004. (http://www.robotcub.org/index.php/robotcub/content/download/614/2215/file/D8.1.pdf)

[5] N.G. Tsagarakis, G. Metta, G. Sandini, D. Vernon, R. Beire, F. Becchi, L. Righetti, J. Santos-Victor, A.J. Ijspeert, M.C. Carrozza and D.G. Caldwell. iCub: the design and realization of an open humanoid platform for cognitive and neuroscience research. International Journal of Advanced Robotics, Vol. 21 No. 10, pp. 1151-75, 2007. (http://www.robotcub.org/misc/papers/07_Tsagarakis_et_al_JAR.pdf)

[6] G. Metta, G. Sandini, D. Vernon, L. Natale, F. Nori. The iCub humanoid robot: an open platform for research in embodied cognition. In PerMIS: Performance Metrics for Intelligent Systems Workshop. Aug 19-21, 2008, Washington DC, USA. (http://www.robotcub.org/misc/papers/08_Metta_Sandini_Vernon_etal.pdf)

[7] G. Metta, G. Sandini, D. Vernon, D.G. Caldwell, N.G. Tsagarakis, R. Beira, J. Santos-Victor, A.J. Ijspeert, L. Righetti, G. Cappiello, G. Stellin, and F. Becchi. The RobotCub project: an open framework for research in embodied cognition. Humanoids Workshop, IEEE–RAS International Conference on Humanoid Robots, 2005. (http://www.robotcub.org/misc/papers/05_Metta_et_al.pdf)