Radiation hard Motion Control components

Motion Control and Automation group

Kristina Jurišić

kristina.jurisic@esss.se

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Overview

- Environmental conditions at ESS
- Example of motion control components and cabling concept in the bunker
- Three strategies for choosing radiation hard components
- Stepper motor: Phytron and Empire Magnetics
- Feedback devices: Resolvers from LTN, Admotec, AMCI and LVDTs
- Switches: Crouzet and Namco
- Next steps and plans

Environmental conditions

- Three different environments to be found at ESS -> three different types of motion control components
- **Normal**: standard temperatures and normally occurring radiation
- **Vacuum**:

  - Low vacuum of 10^{-3} mbar: neutron guides, detector chambers, choppers etc.

  - High vacuum of 10^{-6} mbar: cryogenic sample environment and furnaces
- **Radiation** – mostly neutrons and gamma radiation:
- Mild radiation (tens to hundreds of kGy): cave, beamline collimation
- High radiation (up to 10 MGy): bunker (only a few positioning mechanics, but the majority of the choppers)

Motion Control Components:
Examples for ESS bunker areas, dose rates for 10y

EUROPEAN SPALLATION SOURCE

Cables

Radiation spec cables:
Huber Suhner RADOX 125
(3 MGy)

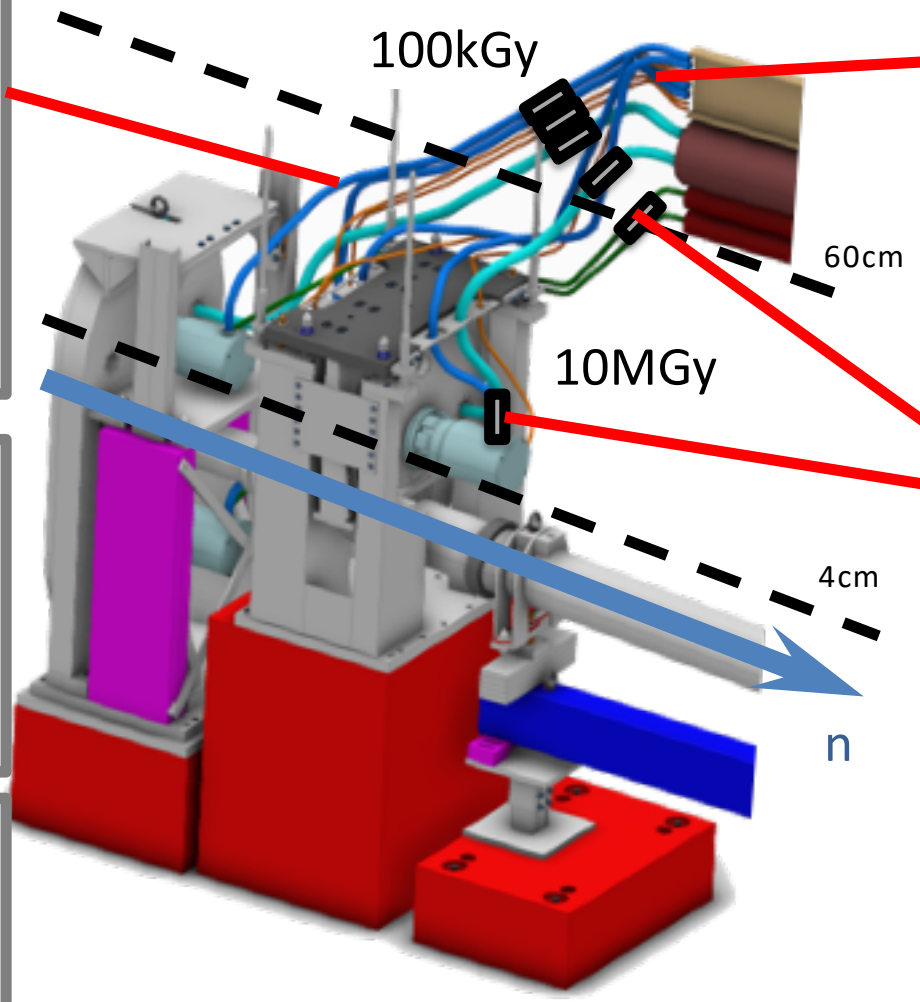
AXON Polyimide TPI
(20MGy)

Sensors

Vibration Sensor:
Vibro-Meter CA901
(10 MGy)

Switches

Mechanical limit switch:
Crouzet 83151 **(10 MGy)**



Cables

Standard cables, PU isolated
(1 MGy, **to be tested!**)

Connectors

Push-Pull, RH ability:
Lemo B-series (Materials:
SS AISI 303 + PEEK plastics)
(10 MGy, to be confirmed!)

Positioning Motors

Stepper motors:
Phytron VSS **(1 MGy)**

Brushless DC motors:
Wittenstein MRSR **(10 MGy)**

Dose numbers given by the supplier are tested with gamma radiation

Process of choosing suitable components

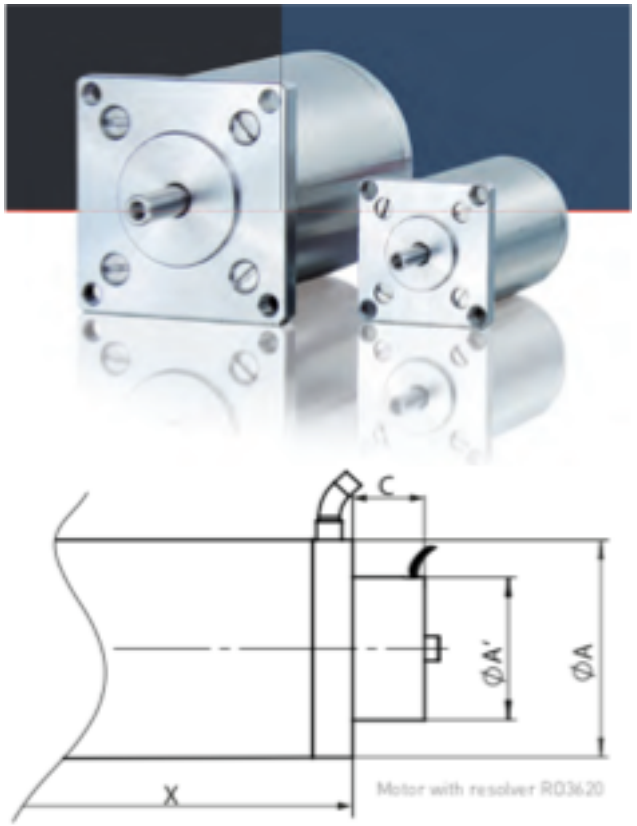
	Advantages	Disadvantages
Radiation certification from supplier	• Easy • Supplier takes the responsibility for component working properly	• Most expensive components costs • Only gamma radiation testing • Only accelerated lifetime testing
Experience from other Neutron facilities	• Testing done with combined neutrons/gamma radiation • Results include full lifetime effects • Supplier knows Neutron facilities as customer	• Subjective, facilities dose rates for scaling not always available • Components used might be already obsolete or changed in material • Most long-term experience is from reactor sources
Our own research / test	• Cheapest component costs • Most up-to-date products • Test adapted to radiation conditions in the facility • Possibility to use this component also for standard environment	• Materials composition often hard to get from supplier • Supplier can change components materials without notice • Component can become obsolete • Research and testing cost time, effort and money • Only accelerated lifetime testing

Stepper motors
Phytron VSS-series

- Radiation hard stepper motor from Phytron, VSS series for ultra high vacuum and harsh environment -> strategy employed: certification from supplier, good experience from other facilities
- Radiation resistance up to 1 MGy, ultra high vacuum up to 10^{-11}mbar

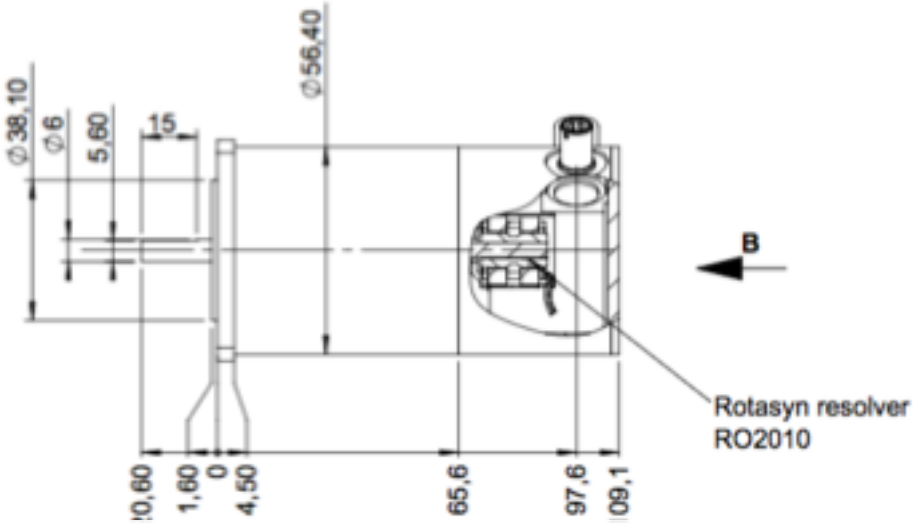
VSS 57.200.2,5-E-UHVG-PT-RS-X

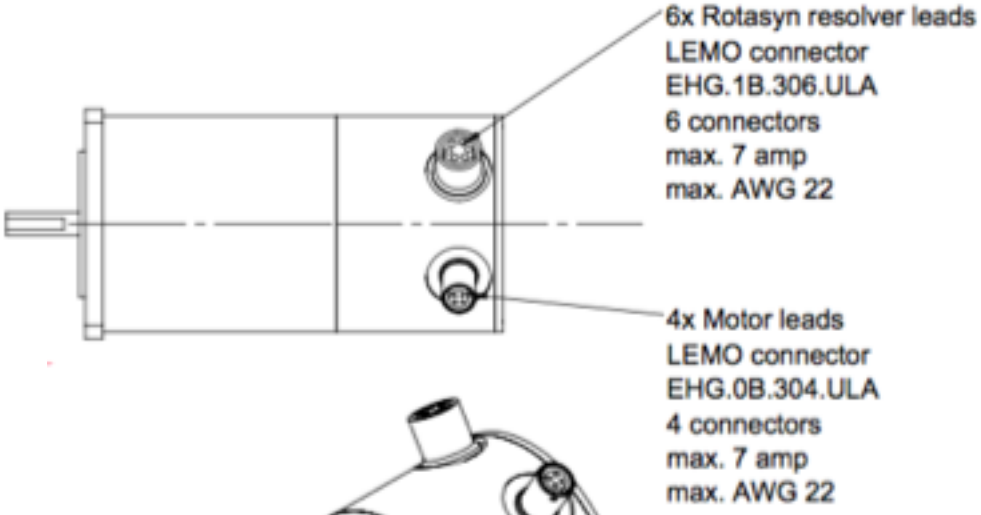
- **57.200.2,5:** Size 57, 200 steps, nominal current 2.5A
- **E**: Second shaft end
- **UHVG:** Ultra high vacuum greased bearing
- Special grease lubrication for radiation and vacuum
- **PT:** PT100 temperature sensor
- **RS**: Brushless resolver RO3620
- **X:** Customised: Shaft diameter 6mm, D-cut (flat sided)
- 500mm Kapton insulated leads for motor and resolver
- Axial lead exit of motor leads, radial for the resolver

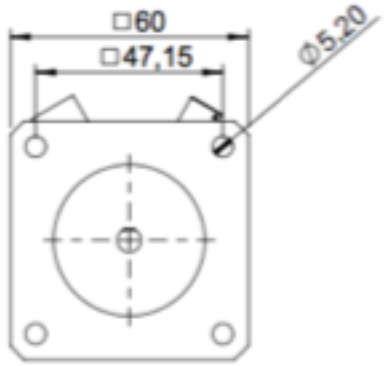


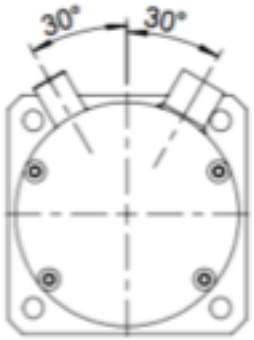
Stepper motors
Phytron VSS-series: ESS customization

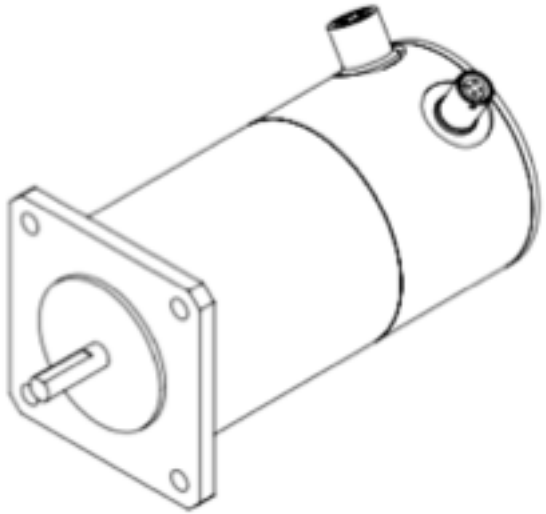
- Modification proposal for future use at ESS:
  - No outgassing holes for non vacuum applications in the bunker
  - Additional housing for resolver and connectors for 3 or 4 flange sizes





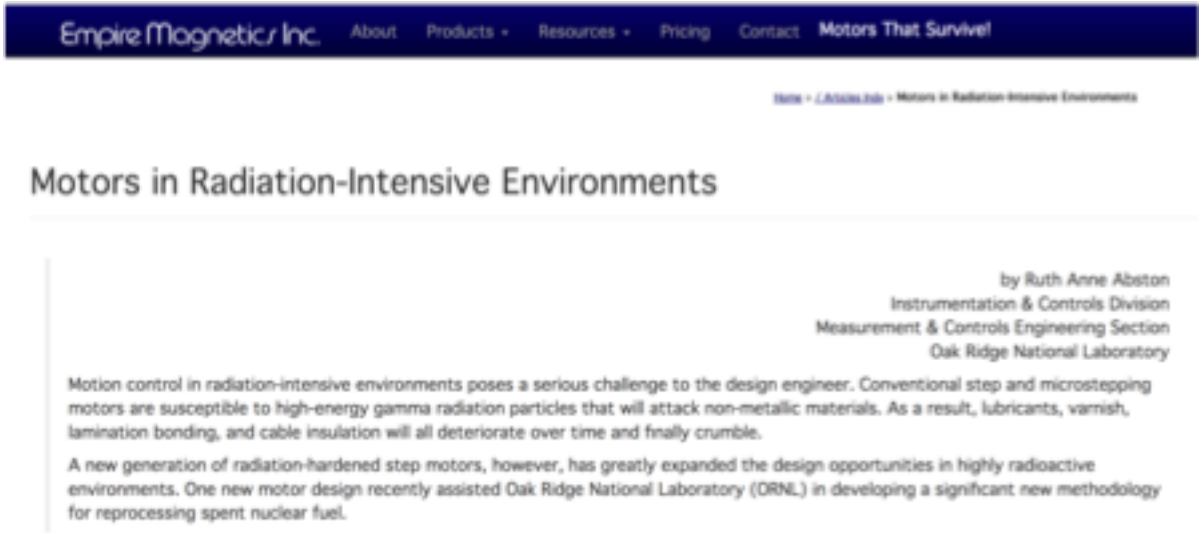






Stepper motors
Empire Magnetics RH series

- Radiation hardened stepper motor from Empire Magnetics -> strategy employed: certification from supplier and good experience from other facility: ANSTO, SNS
- Radiation resistance up to 2 MGy gamma radiation, can be extended up to 10 MGy
- Sizes RH05 to RH42


Empire Magnetics Inc. About Products Resources Pricing Contact Motors That Survive!

Motors in Radiation-Intensive Environments

by Ruth Anne Abston
Instrumentation & Controls Division
Measurement & Controls Engineering Section
Oak Ridge National Laboratory

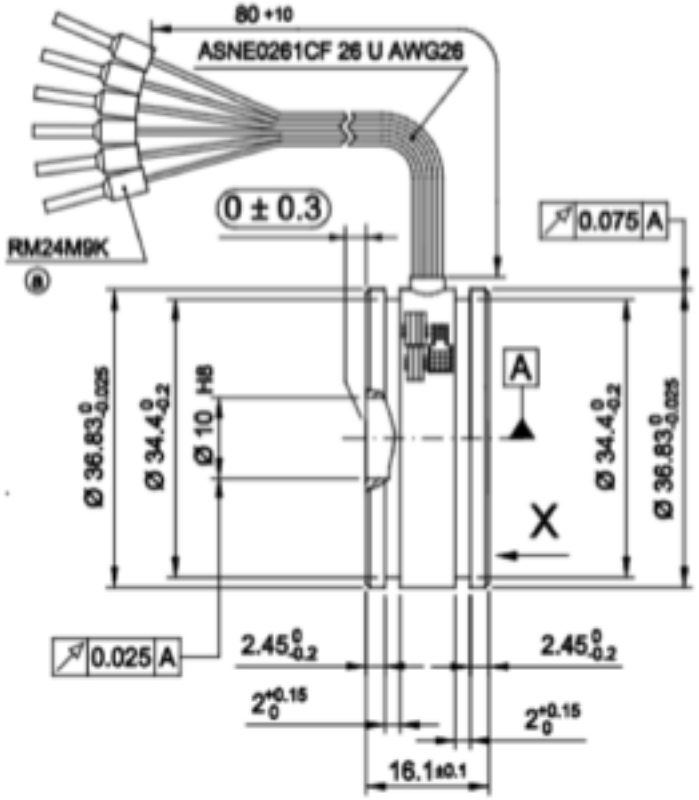
Motion control in radiation-intensive environments poses a serious challenge to the design engineer. Conventional step and microstepping motors are susceptible to high-energy gamma radiation particles that will attack non-metallic materials. As a result, lubricants, varnish, lamination bonding, and cable insulation will all deteriorate over time and finally crumble.

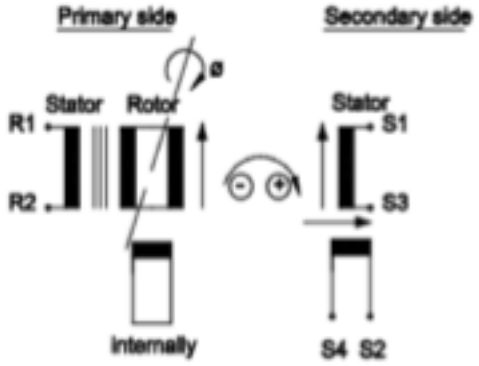
A new generation of radiation-hardened step motors, however, has greatly expanded the design opportunities in highly radioactive environments. One new motor design recently assisted Oak Ridge National Laboratory (ORNL) in developing a significant new methodology for reprocessing spent nuclear fuel.

Feedback devices - Resolver
LTN RE15 series

- Radiation hard hollow shaft resolver from LTN -> strategy employed: certification from supplier and suitable materials used
- Radiation resistance up to 40 MGy

LTN RE-15-S16 resolver





Input : E(R1-R2) = Esin(wt)
Output : E(S1-S3) = Tr x E(R1-R2)cosØ
E(S2-S4) = Tr x E(R1-R2)sinØ
Tr = Transformation ratio
Inner diam. stator = 22.800 min.
Outer diam. rotor = 22.325 max.

Positive counting direction : Rotor cw as viewed (X →)

Filotex® ASN-E0261

CONDUCTOR
① A Stranded Conductor Made of Nickel Plated High Strength Copper Alloy (AWG 26 & 24) or Nickel Plated Copper (AWG 22 to 10).

INSULATION
② 2 FEP/POLYIMIDE/FEP Tapes

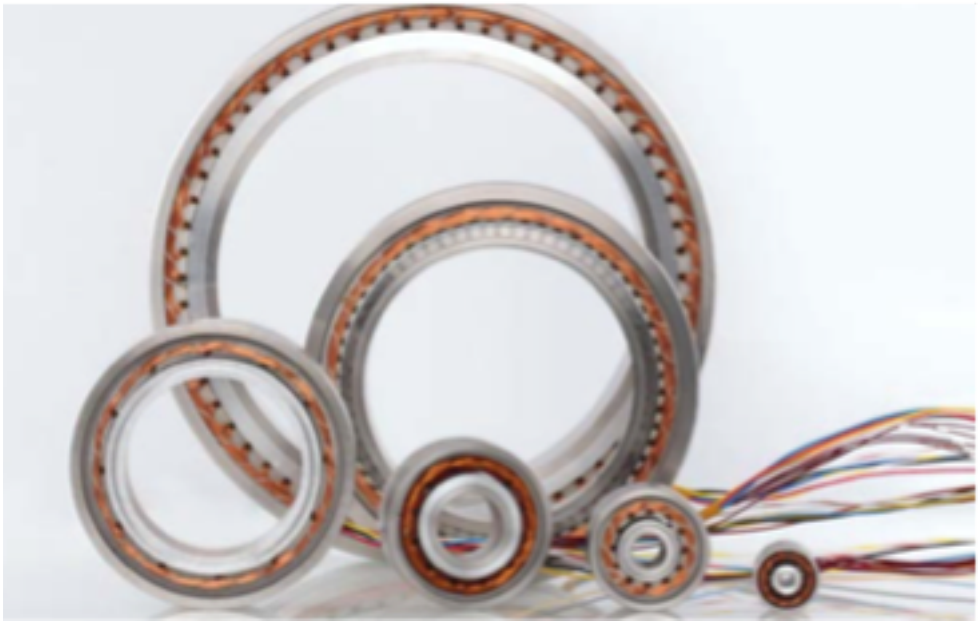
COLOURED TOPCOAT
③ FEP (Laser Markable Optional) or PTFE for cores of Multicores Cables

Feedback devices - Resolver
Admotec Rotasyn series

- Radiation hard resolver from Admotec -> strategy employed: certification from supplier and suitable materials used
- Radiation resistance up to 10 MGy
- With kapton leads, test reports and certificate

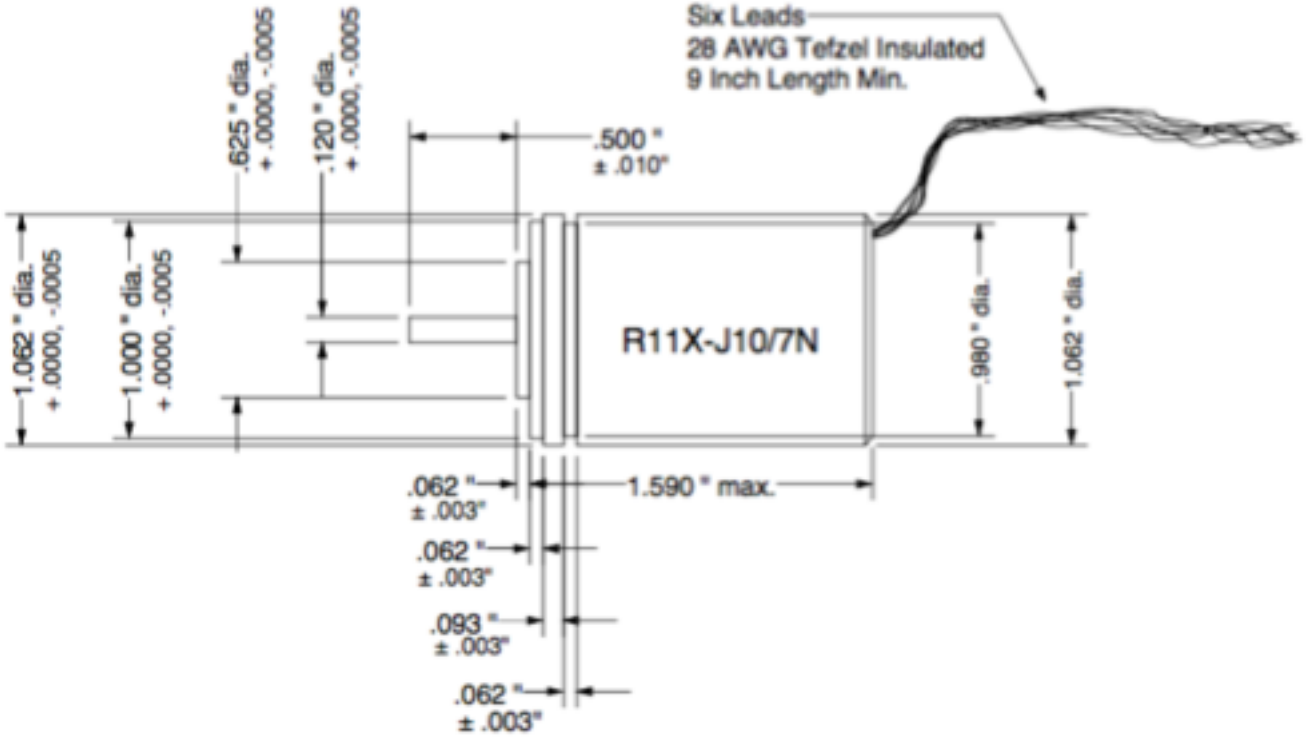
RO2010-K-R004
- **RO2010:** ROTASYN resolver, size 08
- **K**: Kapton insulation
- **R:** standard rotor construction
- **004**: rotor bore size 4mm

RO3620-K-R010
- **RO3620:** ROTASYN resolver, size 15
- **K**: Kapton insulation
- **R:** standard rotor construction
- **010**: rotor bore size 10mm



Feedback devices
AMCI resolver

- Radiation hard brushless resolver from AMCI -> strategy employed: certification from supplier and suitable materials used
- With Tefzel insulation for radiation applications: 10KGy to 300kGy gamma radiation (depending on source of information)



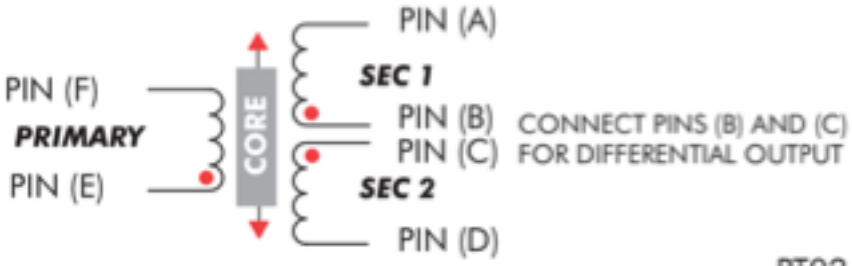
SPECIFICATIONS

Input Voltage:	7.0 V
Input Freq:	5000 Hz
Primary:	Rotor
Input Current:	17.0 mA Max.
Output Voltage:	6.65 V Nom.
Trans. Ratio:	0.95 ± 5%
Accuracy:	7 min. (max. error)
NEMA Rating:	NEMA 1
Wire Insulation:	Tefzil

Feedback devices - LVDT

TE/ MacroSensor HSTA750 series

- **Mild Radiation Environment**
- Stroke ranges from ±1,27 to ±254mm
- Non-Linearity ±0.25% of FR
- Sensitivity from 2.8 to 244 mV/V/mm, (in the differential mode)
- Excitation voltage: $3V_{rms}$, 2.5 to 3.0kHz
- Large temperature range -55 to 200°C
- 300 kGy radiation resistance with order option -080
- With 6p axial connector, sealed to IP68



PT02A-10-6P

Feedback devices - LVDT
Schaevitz (CERN customized)

- **Challenging Environmental Specifications**
- PT100 Resistance Temperature Detector (RTD) inside each LVDT
- 50 MGy radiation resistance
- High EMI immune
- Ratiometric design & testing, corrosion-proof
- Temperature coefficient of sensitivity <50 ppm per °C
- Linearity ranging from 0.1 to 0.04%
- Must operate with varying cable lengths from 50 to 750 meters
- ±40 mm stroke in a 200 mm long package
- Integral 1-meter shielded cable
- Sensitivity > 15 mV/V/mm, (in the differential mode)

Switches
Crouzet cell 83 151

- Radiation hard hermetically sealed cell 83 151 from Crouzet and switches based on it -> strategy employed: certification from supplier and suitable materials used
- The switch combines a snap action switching system with high resistance to shock and vibration in an hermetically sealed case – filled with inert gas (nitrogen-hydrogen mixture)
- Radiation resistance 10.79 MGy gamma radiation

ESSENTIAL CHARACTERISTICS

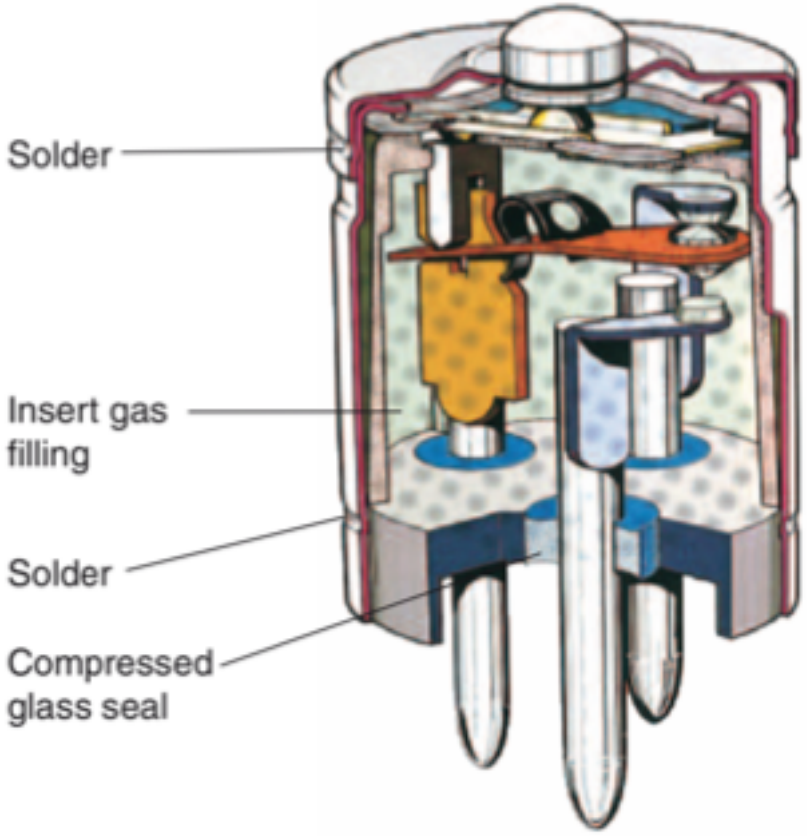
- Switching power from 1 mA to 7 A.
- Operating temperature: -55°C to 150°C : Type 83 151
  -55 °C to 250°C : Type 83 1512
- Operating pressure : 1 bar : Type 83 151
  From 2 to 6 bars : Type 83 1515
- Vibration resistant up to 80 g.
- Shock resistant up to 200 g.
- High level of hermetic sealing: Leakage < 1 x 10^{-6} cm^3 He/S
- Long life: 200,000 cycles.
- Small size: ø 11 x 16.
- Numerous single pole and multipoles operating and fixing options.

Switches
Crouzet cell 83 151

List of materials used in cell 83 151:

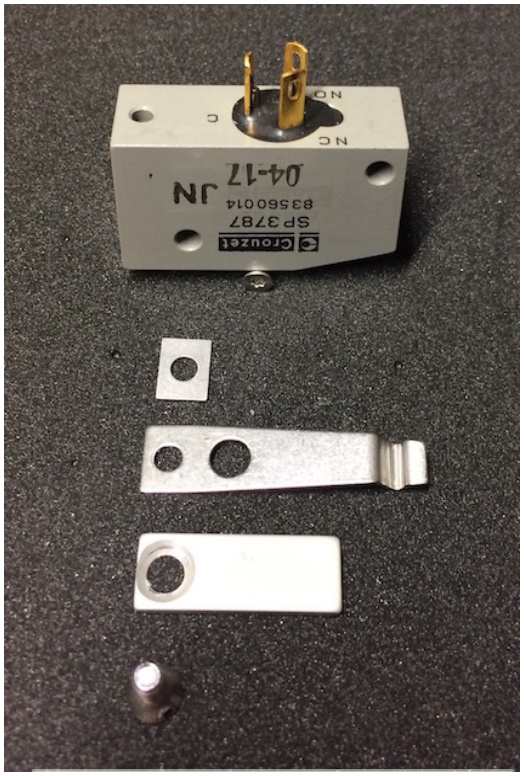
1) Cover:		Z 5 CN 18-08 (annealed)
2) Membrane:		Stainless steel 18-08 Arc 2702 S
3) Plunger:		Stainless steel 18-08 with sulphur
4) Plunger washer:		Z CR 177 (annealed)
- Terminals:	5)	48% Ferronickel baseplate
	6)	Fritted glass pearls
	7)	Ferronickel terminals with copper core and 5 micron electroless nickel plating
8) Common terminal:		UZ 22 N 18 3/4 cold-rolled nickel silver, gold-plated with 3 to 4 microns
9)Top terminal}		1/2 hard nickel silver
10)Bottom terminal}		
11)Contact:		Ag graphite 5/1000
12)Bell insulator:		Micaver
13)Plunger:		Micaver
14)Lever:		Z 12 CN 18/10 – 3/4 hard
15:Spring washer:		ZCR 177 cold-rolled 150 kg/mm2
16:Wire bundle:		Epoxy resin – Stycast 2651
17:Wires:		Filotex 1800

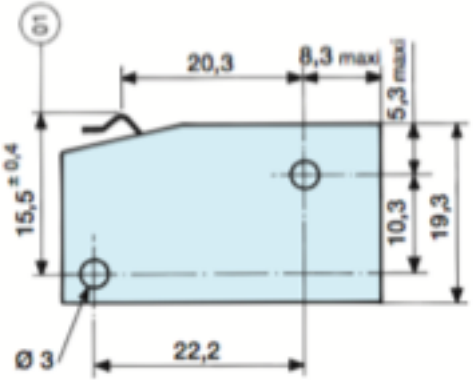
Operating force	Release force	Total travel force	Pre-travel	Differential travel	Overtravel
OF max.	**RF** min.	**TTF** max.	**PT**	**DT** max.	**OT** min.
10 N	1.5 N	20 N	0.15 mm	0.05 mm	0.08 mm



Switches
Crouzet switch 83 560 014

83 560 014





List of parts and materials used:

Component	#	Part	Material	Comment
1. Hermetically sealed cell:	1.1	Housing + membrane	Stainless steel Z5CN18-08	Should be Z5CN18-09?
	1.2	Plunger	Stainless steel Z5CN18-08	assumption
	1.3	Contacts	Silver alloy??	typical material for higher currents
	1.4	Contact support	??	
	1.5	Spring	Stainless steel or copper-bervllium??	typical materials
	1.6	Terminals	Ferronickel with copper core	Gold plating?
	1.7	Sealing	Compressed glass	
	1.8	Filling	Nitrogen-hydro mixture	Inert gas
2. Housing	2.1	Housing (block)	Aluminum alloy AU4G	With dichromate surface treatment
	2.2	Filling	Resin, Epoxy ???	Black filling around the contacts
3. Lever	3.1	Distance piece	Steel, galvanised (zinc)	assumption
	3.2	Lever	Stainless steel	assumption
	3.3	Limit stop	Steel, galvanised (zinc)	assumption
	3.4	Screw	Steel, galvanised (zinc)	assumption

Switches
Crouzet switches based on 83 151 cell

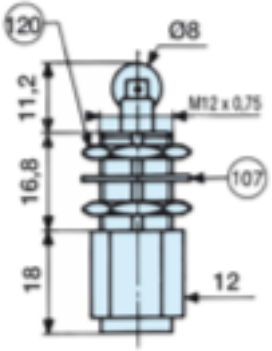
Based on the 83 151 cell:

Switches are not rated as rad hard, only the base cell

83 151 023

83 999 015

83 770 015



83 770 083

83 560 014

Max operating force (N)	10	8.5	12	12	2.5->8
Max. pretravel (mm)	0.25	1.7	0.3	0.3	0.3->0.75
Per. overtravel force (N)	20	22	50	-	50
Max. overtravel (mm)	0.08	0.5	3	2	0.3
Max. differential travel (mm)	0.05	0.5	0.05	0.05	0.3
Op. number	200 000	50 000	100 000	-	100 000

Switches
Crouzet switch 83 999 015 (SP 4863)

- Limit switch qualified for nuclear application -> strategy employed: select a component with lower certification from supplier, look carefully at the materials and test them for higher radiation doses
- Switch is qualified for K3 (no safety application, no radiation test)
- Material from data sheet: Switch cell 83 151, aluminium block, stainless steel roller plunger, K1 qualified cable (should give in total a dose rating of min. 0.85MGy)

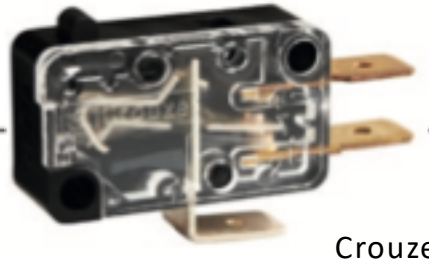
Switches

Crouzet switch based on industry standard 83 161 cell

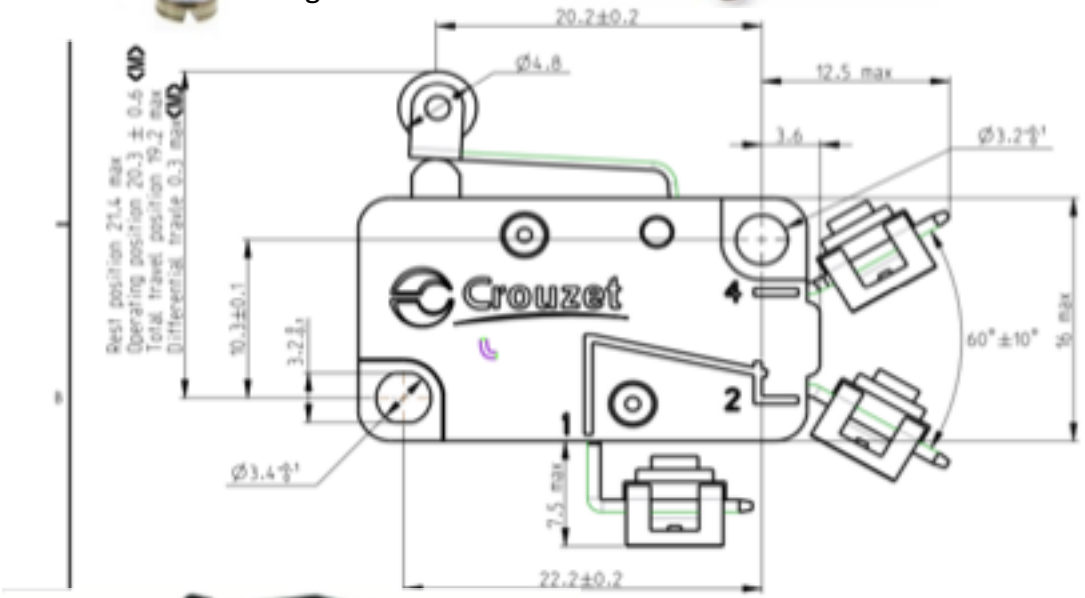
Burgess

Saia

Omron



Crouzet



Customised version for nuclear application.
Has radiation-resistant housing, 180 °C max operating temperature, W5 screw terminals and

Specification
- Max. operating force : 5 N
- Min. release force : 1.5 N
- Max. permitted overtravel force : 20 N
- Temperature range : -20°C to 130°C
- Electrical rating : 24V, 3-4mA
- Electrical and mechanical endurance : 12000 cycles
- Weight : 11.3 g

Customer application
- Normal ambient temperature : 60°C
- Max. temperature : 180°C, 3 hours (following LOss of Coolant Accident profil)
- Seismic activity : Up to 8g in 3 directions
- Radiation : 2 200 KGy (Aging with LOCA)

Marking drawing : MA83160154_001FR

				Lever axis	79210424	1	
				Stainless steel roller lever	79553308	1	
				Rivet	21163407	2	
				Axis	70514112	1	
Spring	79210409	1		Spring	70507775	1	
Blade sub assembly	79210413	1		Blade sub assembly	70507777	1	
Connection	79210418	2		Gold plated connection	70507774	2	
Button	79210478	1		Button	70507773	1	
Cover	79211621	1		Cover	70507772	1	
Housing	79211620	1		Housing	70507771	1	
Designation	*Reference*	*Qte*	*Rep.*	*Designation*	*Reference*	*Qte*	
−				+			
Native Product(s):	**83160 I W5**			*Product Number:*	**83160154**		

The product dates and dimensions not specified on this document are similar to native product.

Special features	Control
- Housing, cover and button in PA6T/66-GF30FR - Adding feature in the housing for magnet location - Spring (material for high temperature range) - Adding rivets - Adding gold plated connections - Stainless steel roller lever	C.C1.DCO.02243.FR

Switches

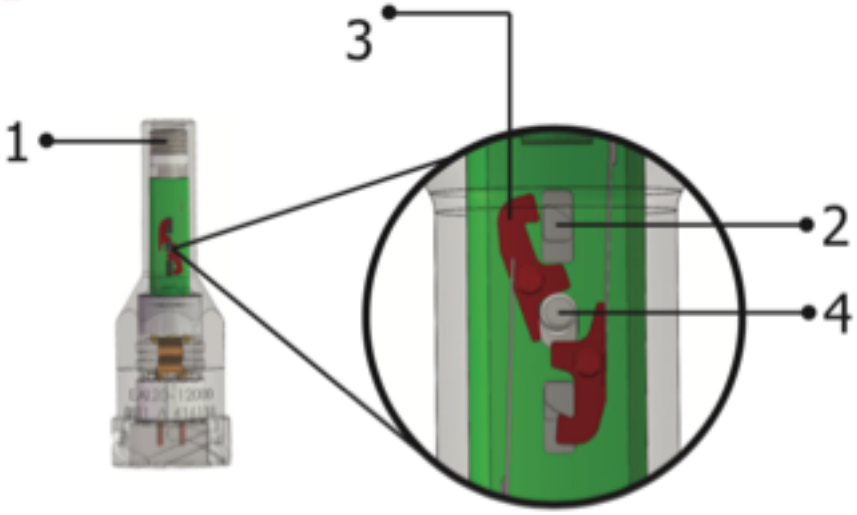
NAMCO EA120 range of nuclear qualified proximity switches

EA120 SPDT Series

NAMCO

Features

- Non-contact magnetically actuated limit switch – no torque on actuator or valve needed
- Qualified to Westinghouse AP1000 Environmental Parameters
- Manufacturing business system complies with 10CFR50, Appendix B, 10CFR Part 21, and ANSI N45.2
- Proprietary SNAP-LOCK® technology that enables internal latching mechanism to eliminate chatter under seismic or high vibration conditions
- Available with QDC milled onto the Stainless steel housing
- Available with pre-wired flying leads
- Gold-plated, fine silver contacts
- High temperature components



Magnetic Prox Type Switch

EA120 SPDT in Harsh Environment Without Accident Conditions

- Operating Temperature: -4° to 212°F (-20° to 100°C)
- Environmental qualifications:
  - Qualified for 100 years 112°F (44°C)
  - 60 years 131°F (55°C)
  - Radiation: 363 MRad gamma
  - Seismic: 8.8G

Product	Description
EA120-51XXX*	SPDT w/ Flying Leads
EA120-52000	SPDT w/ QDC
EC590-44XXX*	Plug In Cable Assy w/ QDC (see pg. 38)
EA120-10001	Target Magnet

Next steps

- After choosing the components and procurement -> test as many as we can in radiation at partner facilities and write test reports
- Sent Crouzet switch 83 560 014 for irradiation to Dubna, Russia at their IBR-II reactor. Switch was exposed to 3MGy fast neutron and gamma radition -> waiting for the test results
- Projects with other facilities -> Commissioning and evaluation of LVDT performance: project with JCNS (FZ Juelich)

- Looking for recommendations and suggestions from colleagues form other facilities -> any comment would be highly appreciated!!!

Thank you!

Questions, comments, suggestions?

References

- ***Switches nuclear explosive atmosphere***, Crouzet switches, Nuclear brochure, 2014
- ***Motors in Radiation-Intensive Environments***, Ruth Anne Abston, Oak Ridge National Laboratory (http://www.empiremagnetics.com/articles/rad_intensive.htm)
- ***CEN SACLAY, Radiation hardness test report***, Withstand to gamma rays of electrical components such as microswitches for use in hot cells, Crouzet
- ***R11X-J10/7N Specification Sheet***, AMCI
- ***For applications where precise Angle Measurement under extreme Conditions is necessary***, Brochure, Admotec Precision AG
- ***Aircraft wires and cables***, Nexans, Catalogue – Issue 2 – 01/10/2003

Links

- https://nepp.nasa.gov/npsl/Wire/insulation_guide.htm, Wire insulation selection guidelines
- https://www.phytron.eu/fileadmin/user_upload/produkte/motoren_aktuatoren/pdf/ds-vacuum-en.pdf
- http://www.empiremagnetics.com/prod_radiation-hardened/radiation_hardened_motors.htm
- https://www.ltn-servotechnik.com/fileadmin/user_upload/data/pdf/LTN-Servotechnik-GmbH-Product-Brochure-EN-PRINT.pdf
- http://www.admotec.com/wordpress/wp-content/uploads/2017/12/RO-Data-Sheet-1607.pdf
- https://www.amci.com/plc-automation-products/r11-size-11-brushless-resolver-sensors
- https://www.te.com/usa-en/product-CAT-LVDT0009.html
- http://media.crouzet.com/crouzet-switches/brochures/valves-and-actuators/Crouzet-Switches_Valves-Actuators_EN.pdf
- https://www.fortive-icg.jp/namco/data/namco_ea120_SP.pdf
- https://www.eiseverywhere.com/file_uploads/d60377f169161f078bf5650db09e3e02_04NamcoMagneticProximitySwitchforValvePositionIndication.pdf