Cost model for the SRF system for the muon collider RCSs

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Motivation

- Provide simple parametric cost model of the SRF systems for the RCS chain
- Will be used for optimization of the magnetic ramp of the RCS to find a correct balance between installed RF voltage and magnetic ramp profile: linear versus sinusoidal.
- It is based on the ILC cost estimate

Summary of the ILC cost summary

- Akira Yamamoto kindly provided summary of the ILC cost developed for the ESPPU-2020:
  - RCS RF system Cost discussion (20 July 2023) · Indico (cern.ch)
- The figure form the summary which will be used in the cost model summarized below:
  - Total cost of ILC250 at 31.5 MV/m: 5260 MU
  - Cryogenics: 6%, High power RF: 8%, SRF and Cryomodule: 28%
  - Power couplers cost 18% of the SRF and Cryomodule
  - Total RF voltage 250 GV, Rep. rate: 5Hz, beam train length 0.73 ms, beam current: 5.8 mA
  - No scaling is done from ILC@31.5MV/m to RCS@30MV/m

Summary of the RCS parameters

RSC		1	2	3	4	ILC
Inj/ej energy	GeV	63/313.8	331.8/750	750/1500	1500/5000	250
Acc. Time	ms	0.34	1.1	2.4	6.4	0.73
Energy gain per turn	GeV	14.8	7.9	11.4	63.6	250
RF voltage per turn	GV	**20.9**	**11.2**	**16.1**	**90**	**250**
Number cavities 9-cells, 1.3GHz, 30MV/m		696	374	536	3000	8000
Peak Beam current per beam	mA	**21.7**	**19.5**	**9.9**	**3.1**	5.8
Energy gain per cavity (RF phase 45 deg)	MV	21.2	21.2	21.2	21.2	31.5
Peak Beam power per cavity for 2 beams	kW	**920.08**	**826.8**	**419.76**	**131.44**	182.7
Duty factor (filling time ~1 ms is included)	1.00E-03	**6.7**	**10.5**	**17**	**37**	8.65
Average beam power/cav for 2 beams	kW	6.16	8.68	7.14	4.86	1.58

Zero-order cost model and RSC cost

ILC	rel cost	abs cost
paramter	[%]	[MU]
Total	100	5260
HPRF (klystrons, WG)	8	420.8
SRf and cryomodule	28	1472.8
Cryogenics	6	315.6
Sum	42	**2209.2**
Total voltage	[GV]	250
Zero-order cost model		
Cost per GV: C0	**[MU/GV]**	**8.8368**

RSC		1	2	3	4	All
RF voltage per turn	GV	20.9	11.2	16.1	90	
C0	**MU**	**185**	**99**	**142**	**795**	**1221**

Very simple, TOO simple probably, since the beam parameters are very different and pulse structure is different in some of the RCS form the ILC ones

First-order cost model refinement

HPRF (klystrons, WG)	**MU**	**420.8**
energy gain	[GV]	250
peak beam current	mA	5.8
Cost per GV per mA: C1P		
cost of HPRF: C1P*V*cosPhi*Ib	**MU/(GV*mA)**	**0.29**
SRf and cryomodule	**MU**	**1472.8**
FPC (18%)	MU	265.104
Cost per GV per mA: C1FPC		
cost of FPC: C1FPC*V*cosPhi*Ib	**MU/(GV*mA)**	**0.18**
cavities and CM (82%)	MU	1207.7
Cost per GV: C1SRF		
cost of SRF: C1SRF*V	**[MU/GV]**	**4.83**
Cryogenics	**MU**	**315.6**
train length :tb	ms	0.73
filling time: tf	ms	1
repetition frequency	Hz	5
Duty factor: (tb+tf)*frep	1.00E-03	8.65
Cost per GV per 1e-3: C1C		
Cost of Cryogenics: C1C*V*DutyF	**[MU/GV/1e-3]**	**0.146**

RSC		1	2	3	4	All
Acc. Time	ms	0.34	1.1	2.4	6.4	
Energy gain per turn	GeV	14.8	7.9	11.4	63.6	
RF voltage per turn	GV	20.9	11.2	16.1	90	
Peak Beam current per beam	mA	21.7	19.5	9.9	3.1	
Peak Beam power per cavity for 2 beams	kW	920	827	420	131	
Duty factor with fill. time 1 ms	1E-3	6.7	10.5	17	37	
C1P	MU	186	89	66	114	456
+						
C1FPC	MU	117	56	41	72	287
+						
C1SRF	MU	101	54	78	435	668
+						
C1C	MU	20	17	40	486	566
=						
Total C1	**MU**	**425**	**217**	**224**	**1107**	**1974**

More accurate cost model gives almost x2 higher cost for the RCSs

Conclusions

- Zero-order parameterized cost model has been proposed. It does not reflect any differences in the beam power between ILC and MC RCSs.
- First-order parameterized cost model has been developed considering difference in the beam power and duty factor between ILC and MC RCS.
  - Cost of high power RF and FPC is propositional to the beam peak power
  - Cost of cryogenic is proportional to the duty factor
- It gives very rough cost estimate but provide some dependence of the cost on the main parameters of the RCSs. That is the main objective for the RCS optimization