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Costing Algorithm for Magnet Systems

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Summary

In this note we describe a costing algorithm for systems of magnets. The algorithm gives a good approximateion to the magnet system cost, taking into account details of superconducting cable manufacture.

1. Introduction

Cost is one of the quantities that is used to compare magnetic systems. It depends on fundamental design choices, as well as detailed layout. Here we report an algorithm that can be used to determine the cost of a magnetic system formed of several coils. The algorithm is mainly aimed at the superconducting cable and magnet design, and therefore it is strongly simplified for all aspects regarding auxiliaries. Note that in particular all costs related to power converter (apart from operation) are neglected.

The basis of the algorithm for magnet costing are studies performed for fusion reactors as well as similar studies performed on SMES systems. All costs are expressed in this note using 1997 US $.

The cost is split in Capital (total investment for the construction of the magnet and related systems) and Operation (charges on a yearly basis and plant maintenance).

2. Capital cost

The total capital cost of the system is estimated as the sum of material and manufacturing costs:

Capital ($) = *Magnet + Cryostat + Auxiliaries + Cryoplant*

Magnet	*cost of magnets ($)*
Cryostat	*cost of the cryostat and thermal screens ($)*
Auxiliaries	*cost of auxiliary systems ($)*
Cryoplant	*cost of cryogenic installation ($)*

2.1 Magnet Cost

The magnet cost are computed from the raw material costs and the magnet manufacturing operations. Note that for Nb_3Sn a heat treatment is necessary, while for NbTi this cost is not applicable.

Magnet ($) =	*Conductor + Insulation + Reinforcement + Winding + Heat + Structure + Supports*

Conductor	*cost of conductor material and manufacturing ($)*
Insulation	*cost of conductor insulation operation ($)*
Reinforcement	*cost of reinforcement structures in the winding pack ($)*
Winding	*cost of winding operation ($)*
Heat	*cost of heat treatment ($)*
Structure	*cost of the mechanical structure($)*
Supports	*cost of mechanical supports ($)*

2.1.1 Conductor Cost

Conductor ($) =	*Strand + CoWound + Jacket + Cabling + Jacketing*

Strand	*cost of superconducting strands ($)*
CoWound	*cost of cowound stabilizer strands ($)*
Jacket	*cost of jacket ($)*
Cabling	*cost of cabling operation ($)*
Jacketing	*cost of jacketing operation ($)*

Note that the following figures already take into account contingencies for strand rejection and cabling loss.

2.1.1.1 Superconducting Strands Cost

Strand ($) =	*Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*	
Weight	*weight of superconducting strand in a coil (Kg)*	
Cost/Kg	*cost of superconducting strand per Kg of material*	
	Nb3Sn strand	*650 ($/Kg)*
	NbTi strand	*180 ($/Kg)*

2.1.1.2 Co-wound Stabilizer Strands Cost

CoWound ($) =	*Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*

Weight	*weight of the co-wound stabilizer strands in a coil (Kg)*	
Cost/Kg	*cost of co-wound stabilizer strand per Kg of material*	
	Cr coated Cu strand	*17 ($/Kg)*

2.1.1.3 Jacket Cost

Jacket ($) = *Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*	
Weight	*weight of the jacket in a coil (Kg)*	
Cost/Kg	*cost of finished jacket per Kg of material*	
	steel (316 LN)	*52 ($/Kg)*
	Al	*42 ($/Kg)*
	incoloy (908)	*87 ($/Kg)*

2.1.1.4 Cabling Cost

Cabling ($) = *Ncoils * Length * Cost/m*

NCoils	*number of coils in the system (-)*	
Length	*conductor length in a coil (m)*	
Cost/m	*cabling cost per unit length of finished conductor*	
	up to 5 stages	*170 ($/m)*

2.1.1.5 Jacketing Cost

Cost ($) = *Ncoils * Length * Cost/m*

NCoils	*number of coils in the system (-)*	
Length	*conductor length in a coil (m)*	
Cost/m	*jacketing cost per unit length of finished conductor*	
	thin-walled jackets	*54 ($/m)*
	thick-walled jackets	*100 ($/m)*

2.1.2 Insulation Cost

Insulation ($) = *Ncoils * Length * Cost/m*

NCoils	*number of coils in the system (-)*	
Length	*conductor length in a coil (m)*	
Cost/m	*insulation cost per unit length of wound conductor*	
		70 ($/m)

2.1.3 Winding Reinforcement Structure Cost

*Reinforcement ($) = Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*	
Weight	*weight of reinforcement structure in the winding pack of a coil (Kg)*	
Cost/Kg	*material and manufacturing cost per unit weight of structural material*	
	Steel	*60 ($/Kg)*
	Al	*50 ($/Kg)*
	Incoloy	*95 ($/Kg)*

2.1.4 Winding Cost

*Winding ($) = Ncoils * Length * Cost/m*

NCoils	*number of coils in the system (-)*	
Length	*conductor length in a coil (m)*	
Cost/Kg	*winding cost per unit length of wound conductor*	
	wind(+react)	*750 ($/m)*
	wind+transfer(+react)	*1800 ($/m)*

2.1.5 Heat Treatment Cost

*Heat ($) = Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*	
Weight	*weight of a coil (Kg)*	
Cost/Kg	*heat treatment cost per unit weight of structural material*	
	Nb3Sn	*28 ($/Kg)*
	NbTi	*NA*

2.1.6 Structure Cost

*Structure ($) = Ncoils * Weight * Cost/Kg*

NCoils	*number of coils in the system (-)*	
Weight	*weight of the structural material of a coil (Kg)*	
Cost/Kg	*material cost per unit weight of structure in a finished coil*	
	Steel	*20 ($/Kg)*
	Al	*10 ($/Kg)*
	Incoloy	*55 ($/Kg)*

2.1.7 Supports Cost

*Cost ($) = NSupports * Weight/NSupports * Cost/Kg*

NSupports	*number of supports in the system (-)*
Weight	*total weight of the system of coils supported (Kg)*
Cost/Kg	*cost per unit of supported weight*
	0.5 ($/Kg)

2.2 Cryostat Cost

*Cryostat ($) =* *Surface * Cost/*$m^2$

Surface	*surface of cryostat (*m^2*)*
Cost/m^2	*cost per unit surface of cryostat*
	6000 ($/*$m^2$)*

2.3 Auxiliaries Cost

Auxiliaries ($) = *CurrentLeads*

CurrentLeads *cost of current leads ($)*

2.3.1 Current Leads Cost

CurrentLeads ($) = *NLeads * Current * Cost/A*

NLeads	*number of current leads in the system (-)*	
Current	*nominal operating current (A)*	
Cost/A	*cost of current lead per unit current carried*	
	low-Tc leads	*2.7 ($/A)*
	high-Tc leads	*5.5 ($/A)*

2.4 Cryoplant Cost

The cost of a cryogenic plant with cold-end installed power in the range 0.1 to 30 kW can be estimated using:

Cost ($) = *1770000 * CryoPower**0.7*

CryoPower *installed cryogenic (cold-end) power (kW)*

For a smaller cold-end installed power, in the range 0.5 to 60 W, the cost can be estimated using:

Cost ($) = *45000 * CryoPower**0.5*

CryoPower *installed cryogenic (cold-end) power (W)*

3. Operation cost

The operation cost for the system is estimated as the sum of electricity cost for the operation, operating costs for the cryogenic plant and annual capital charge:

Operation ($) = *Electricity + CryoOperation + Charge*

Electricity	*cost of electric power necessary for operation (power converter, auxiliaries, excluding cryogenic plant) ($)*
CryoOperation	*cost for the operation and maintenance of the cryogenic plant (including electricity costs) ($)*
Charge	*annual charge on capital investment ($)*

3.1 Electricity cost

The electricity cost is determined based on the power needed by the plant (excluding cryogenic operation):

Electricity ($) = *360.0 * 24.0 * Power * Kwh*

Power	*installed power for operation (power converter and auxiliaries) (kW)*
Kwh	*cost of the KWh ($)*

3.2 Cryogenic plant operation cost

The cryogenic plant operation and maintenance is computed using the following scaling law that does not include depreciation of the plant:

CryoOperation ($) = *2 * 24.0 * CryoPower**0.78 * Kwh**0.56*

CryoPower	*installed cryogenic (cold-end) power (kW)*
Kwh	*cost of the KWh ($)*

3.3 Capital charge

The annual capital charge is estimated as 5 % of the total capital cost:

Charge ($) =* *0.05 * Capital ($)