Genetic Algorithm Based Multi-Objective Optimization of Electromagnetic Components using COMSOL® and MATLAB®

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Introduction

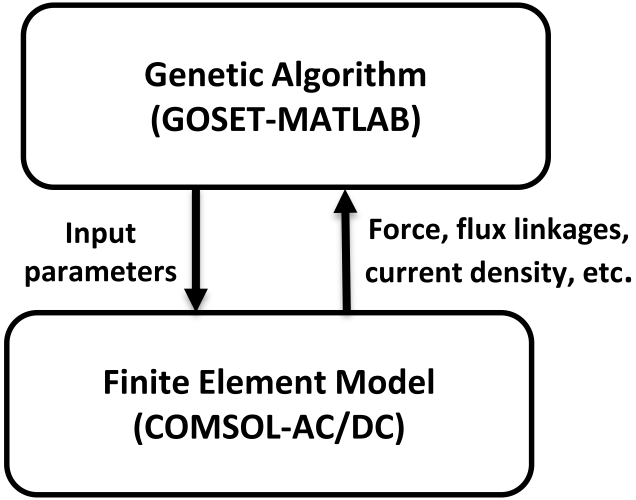
Problem:

- Optimum design of an electromagnet
- Minimize competing objectives (e.g. loss, volume)

Methodology:

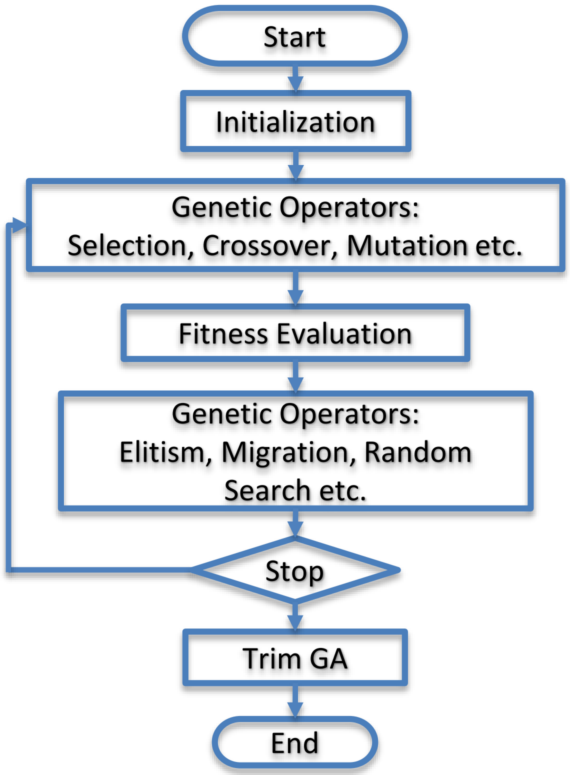
- Global optimization technique – Genetic algorithm (GA)
    - Design space and parameters
    - Design requirements and constraints
    - Target objectives
- Computationally efficient model (e.g. COMSOL)

Computation Methodology



- GA coupled with COMSOL
- GA produces Pareto-optimal front
- COMSOL calculates model results
- LiveLink for MATLAB

Genetic Algorithm

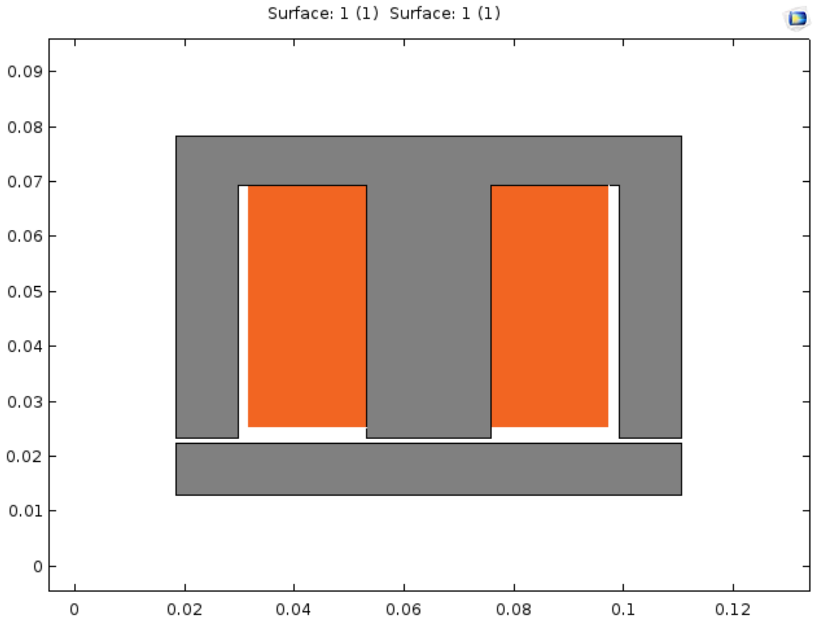


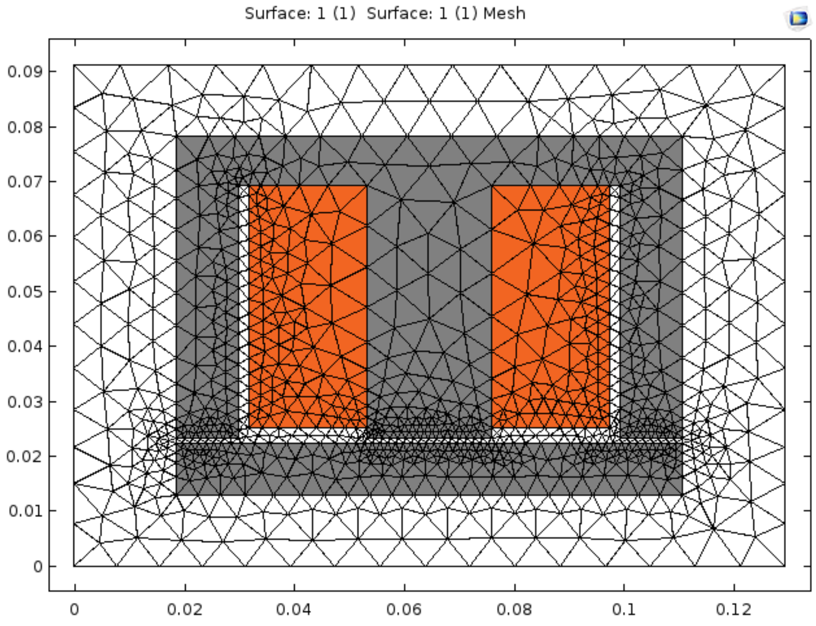
- GOSET – a GA toolbox in MATLAB
- GOSET is highly customizable for a given optimization problem
- Information exchange during fitness evaluation stage using LiveLink for MATLAB

S. D. Sudhoff, GOSET: For Use with MATLAB, Manual Version 2.3, Purdue University, School Elec. And Comp. Eng., West Lafayette, USA, Sept. 17 (2007)

COMSOL Model (Electromagnet)

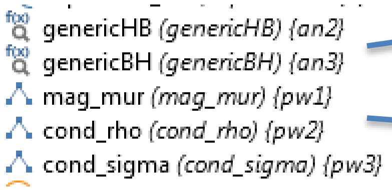
Fully parameterized model

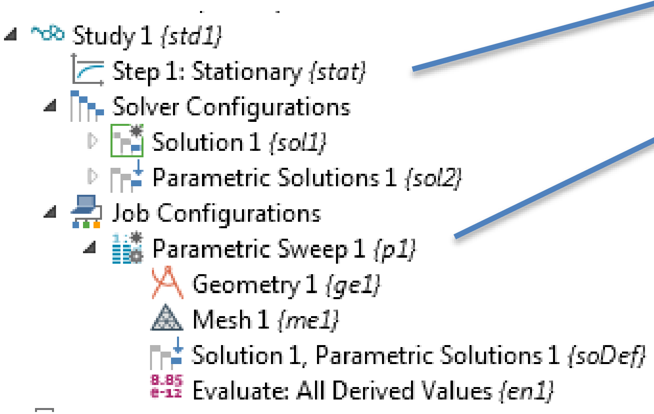




AC/DC and LiveLink for MATLAB Modules

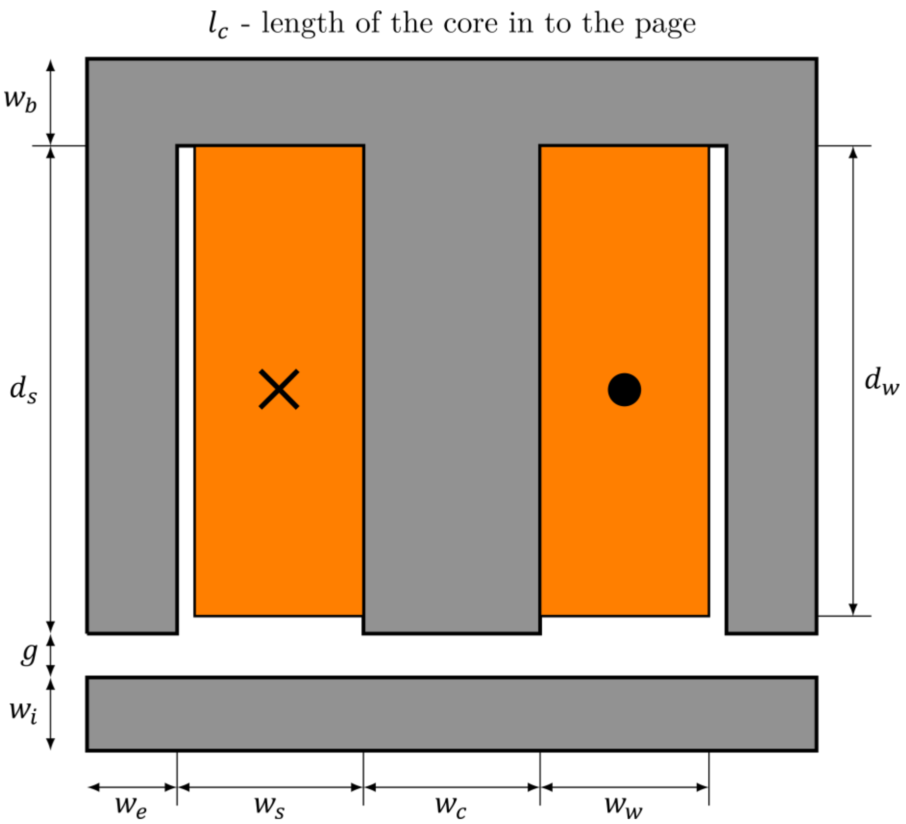
COMSOL Model…





- Generic H(B) and B(H) relations: interpolation and Kronecker delta functions
- Conductor material properties: Piecewise functions
- A magneto-static study is setup to evaluate force, current density, flux linkage, etc.
- Parametric Sweep job is used to evaluate multiple magneto-static analyses

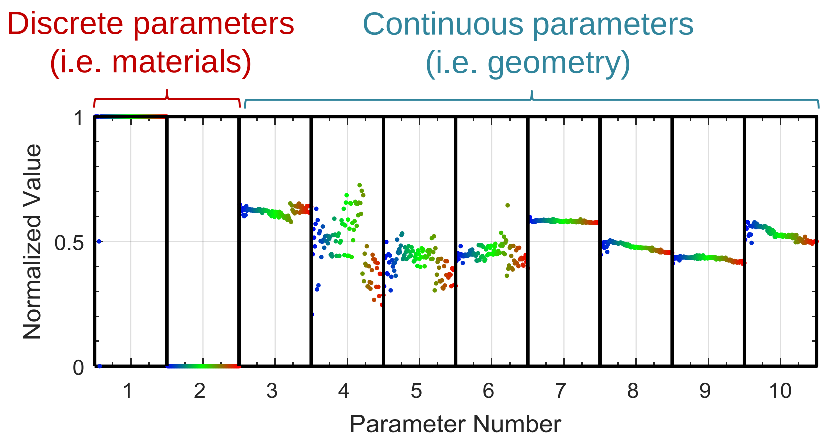
Design of an Electromagnet

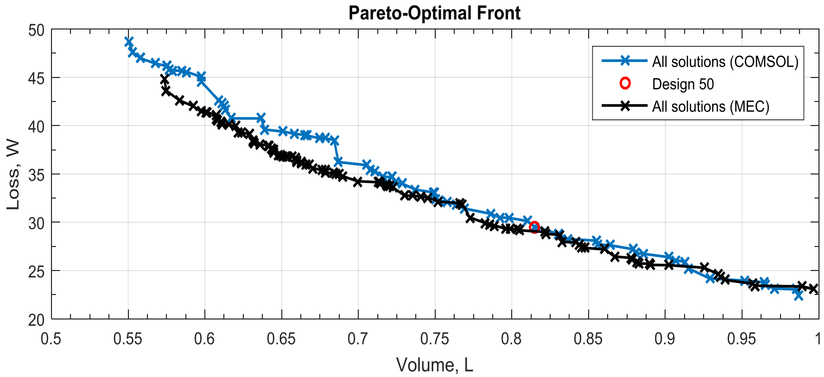


Parameter	Symbol	Description	Range	
			min	max
1	T_{cr}	Steel core material	1	5
2	T_{cd}	Conductor material	1	2
3	w_c	Width of the core center	2 mm	0.1 m
4	$\frac{2w_e}{w_c}$	Twice end-leg width to core center width ratio	0.5	1.5
5	$\frac{2w_i}{w_c}$	Twice I-core width to core center width ratio	0.25	1.5
6	$\frac{2w_b}{w_c}$	Twice E-core base width to core center width ratio	0.25	1.5
7	a_c	Desired cross-sectional conductor area	1e-9 m^2	1e-4 m^2
8	N	Desired no. of turns	1	1000
9	N_w	Desired slot width in conductors	1	1000
10	N_d	Desired slot depth in conductors	1	1000

S. D. Sudhoff, Power Magnetic Devices: A Multi-Objective Design Approach, 154-177, John Wiley & Sons, New York (2014)

Results





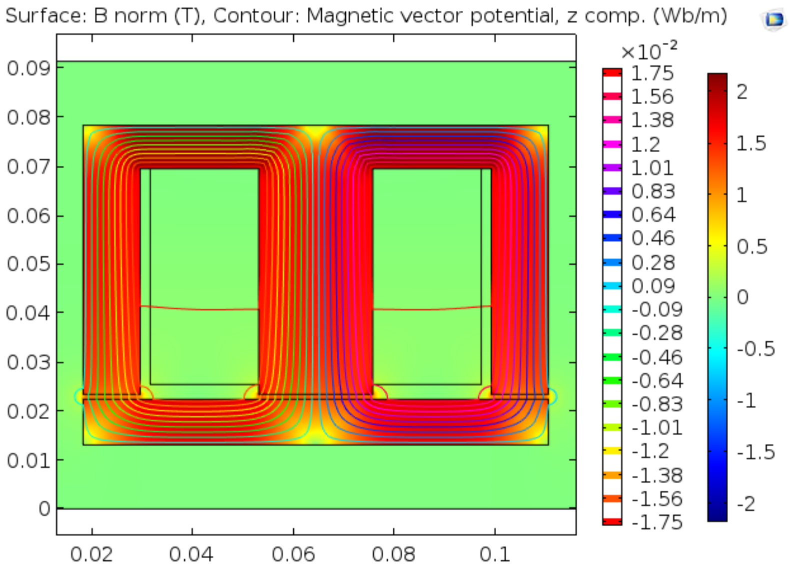
Design Requirements

- Force > 2500 N
- Current density < 7 A/mm^2
- Current < 5 A
- Volume < 1 L
- Packing factor < 0.7

Optimization Process

- 200 individuals for 200 generations
- The optimization took about 30 hours
- Computer specs: 24 CPU cores @ 2.5 GHz, and 128 Gb RAM

Results: Design 50



Constraints	Design 50
Force	2519 N
Current density	2.99 A/mm^2
Current	2.46 A
Volume	0.815 L
Packing factor	0.698

Design Parameters

Symbol	Description	Design 50
T_{cr}	Steel core material	Hiperco50
T_{cd}	Conductor material	Copper
w_c	Width of the core center	2.26 cm
$\frac{2w_e}{w_c}$	Twice end-leg width to core center width ratio	1.00
$\frac{2w_i}{w_c}$	Twice I-core width to core center width ratio	0.826
$\frac{2w_b}{w_c}$	Twice E-core base width to core center width ratio	0.784
a_c	Desired cross-sectional conductor area	0.826 mm^2
N	Desired no. of turns	804
N_w	Desired slot width in conductors	20.2
N_d	Desired slot depth in conductors	41.2

Conclusion

- A global optimization approach used to design an electromagnet
    - Considers a large design space (i.e. 10 degrees of freedom)
    - Accounts for various constraints
    - Evaluate tradeoff between objectives
- Target design chosen and evaluated from Pareto-optimal front
- Knowledge of Pareto-optimal aids in system-level design
- Extendable to other magnetic devices