Optimal design of electric motors

7.5 kW, 380 V, 50 Hz, 4 poles, three-phase

Optimal design of electric motors

Electric motors are widely used in industrial and domestic applications

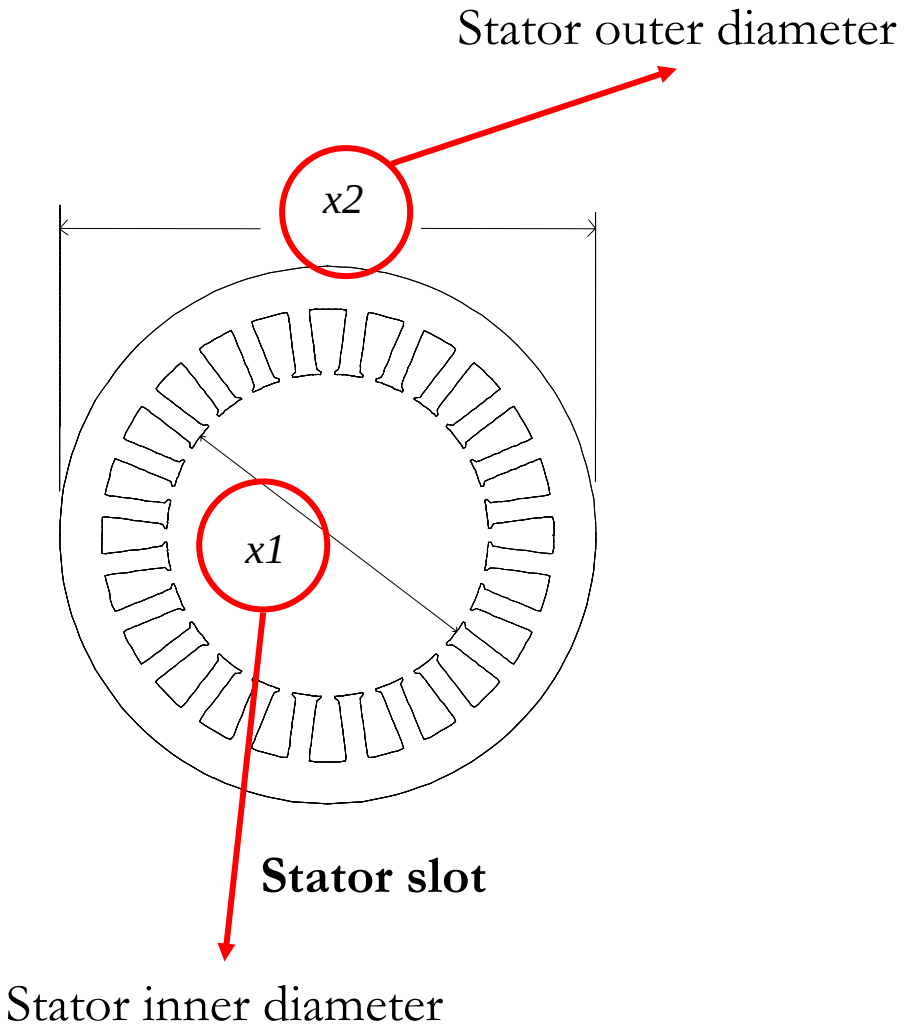
+

Optimized design can improve the efficiency of the motors

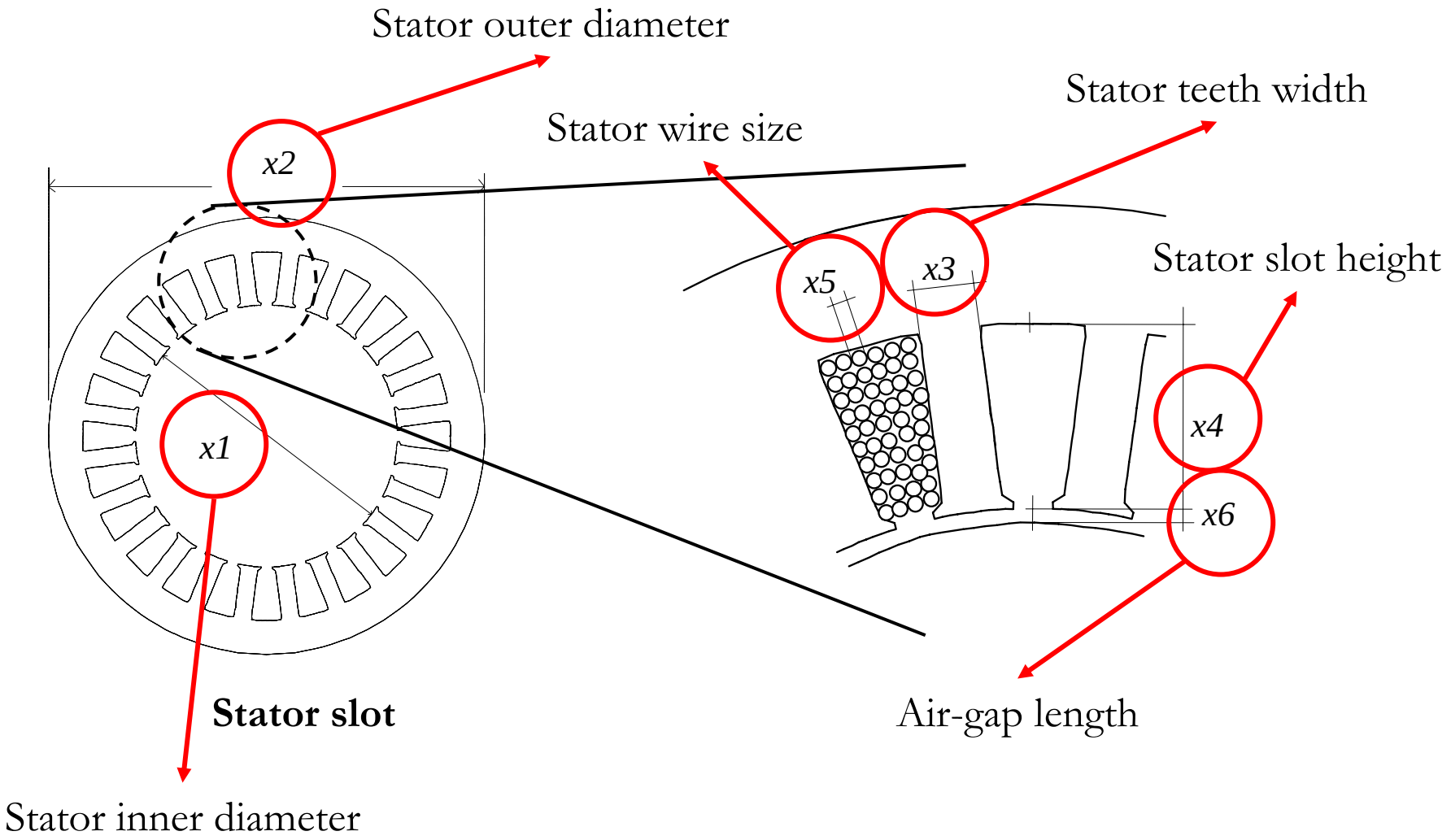
⇩

Reduction of energy consumption

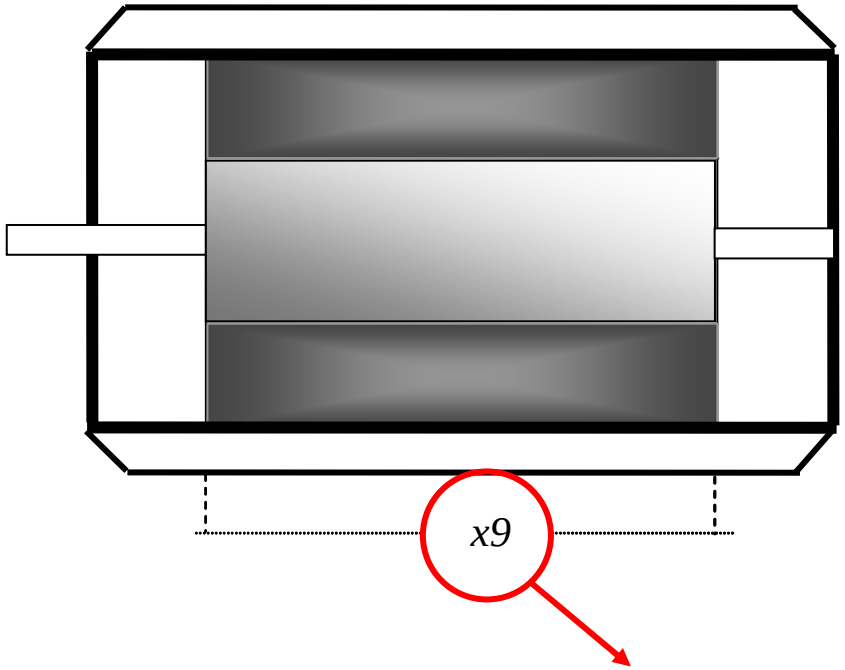
Independent Variables – Design Parameters



Independent Variables – Design Parameters

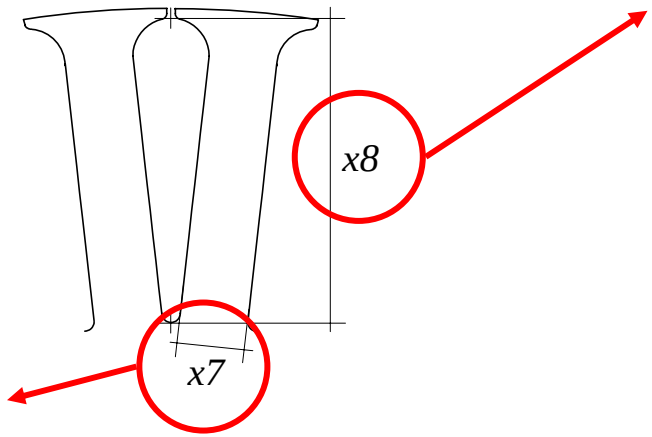


Independent Variables – Design Parameters



Stack length

Rotor slot height :



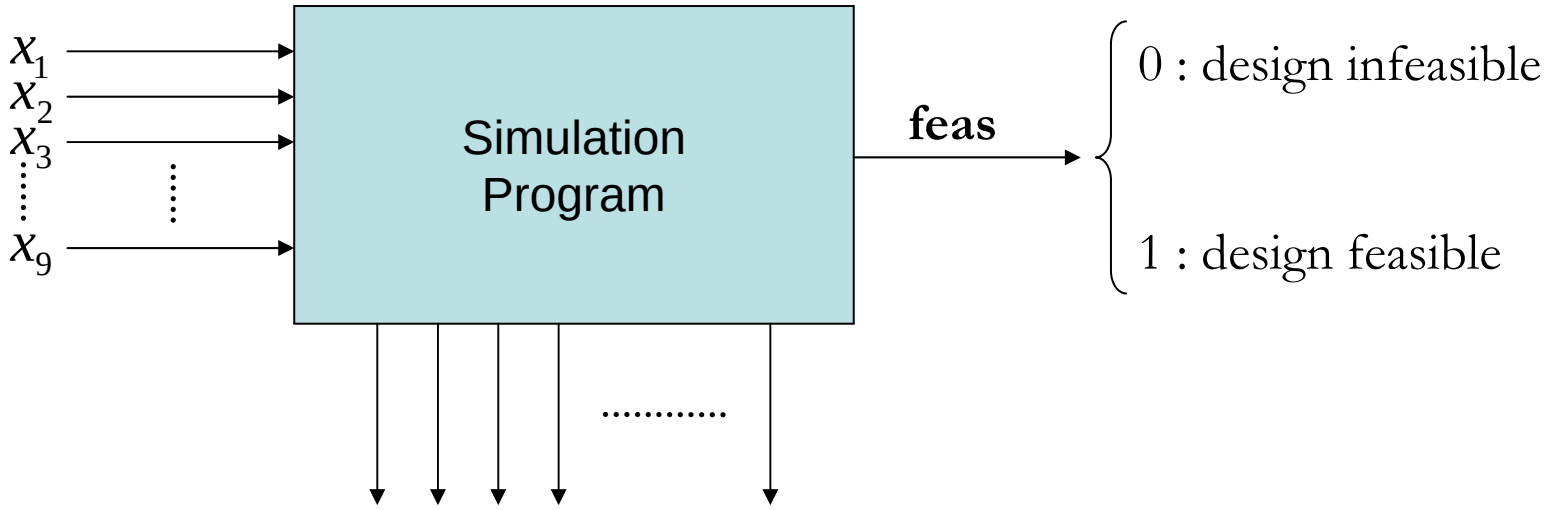
Rotor teeth width

Rotor slot

Independent Variables – Design Parameters

Stator inner diameter :	$120.0mm \le x_1 \le 130.0mm$
Stator outer diameter :	$180mm \le x_2 \le 220mm$
Stator teeth width :	$4.5mm \le x_3 \le 6.5mm$
Stator slot height :	$16mm \le x_4 \le 19mm$
Stator wire size :	$1.4mm^2 \le x_5 \le 4.0mm^2$
Air-gap length :	$0.3mm \le x_6 \le 0.5mm$
Rotor teeth width :	$3.5mm \le x_7 \le 5mm$
Rotor slot height :	$16mm \le x_8 \le 18.5mm$
Stack length :	$140mm \le x_9 \le 190mm$

Simulation and Performance Evaluation



Performances/features

Manufacturing cost
Operating cost
Rated efficiency
Rated power
Power factor at rated load
Starting current
Starting torque
Breakdown torque
Stator slot fullness
Stator winding temperature
Rotor bars temperature
Induction in the stator and rotor teeth
Rated slip

Nonlinear Constraints

Rated power:	$pwi \leq 7560W$
Power factor at rated load:	$\cos\varphi \geq 0.8$
Starting current:	$I_{st} \leq 67A$
Starting torque:	$T_{st} \geq 97Nm$
Breakdown torque:	$T_{\max} \geq 140Nm$
Stator slot fullness:	$k_{ssf} \leq 0.55$
Stator winding temperature:	$T_{cu} \leq 130^{o}C$
Rotor bars temperature:	$T_{al} \leq 150^{o}C$
Induction in the stator teeth:	$1.2T \leq H_{st} \leq 1.8T$
Induction in the rotor teeth:	$1.2T \leq H_{rt} \leq 1.8T$
Rated slip:	$RS \leq 0.05$

Initial Feasible Design

Existing motor having
a Rated Efficiency of 88.38%

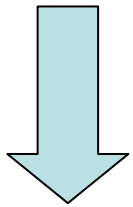
(Real Measured Efficiency of 84.2%)

$$
\begin{cases}
x_1 = 126.6mm \\
x_2 = 200mm \\
x_3 = 5.5mm \\
x_4 = 17.5mm \\
x_5 = 1.5727mm^2 \\
x_6 = 0.4mm \\
x_7 = 4mm \\
x_8 = 17.8mm \\
x_9 = 160mm
\end{cases}
$$

Problem Statement

find x^* such that $f(x^*) \leq f(x)$

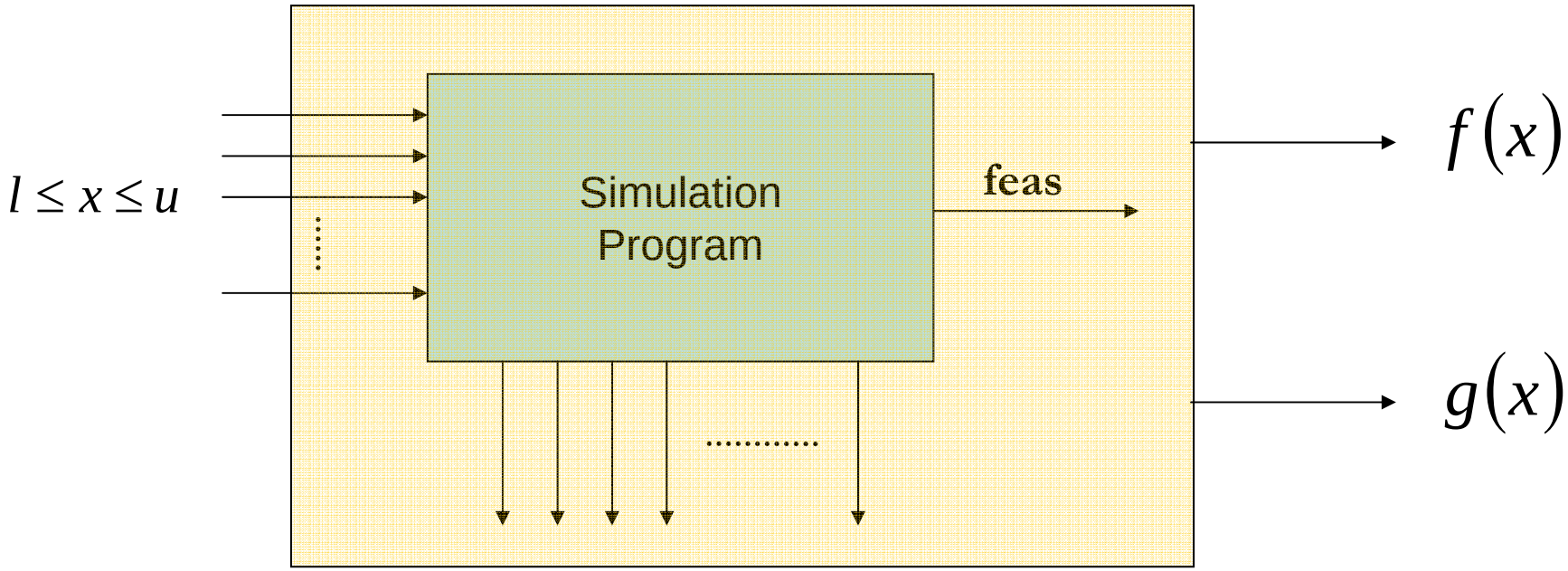
for all $x \in \{x : l \leq x \leq u,\ g(x) \leq 0\}$



$$\begin{aligned} \arg\min \quad & f(x) \\ \text{s.t.} \quad & g(x) \leq 0 \\ & l \leq x \leq u \end{aligned}$$

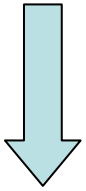
Problem Statement

$$\begin{aligned} \arg\min \quad & f(x) \\ \text{s.t.} \quad & g(x) \le 0 \\ & l \le x \le u \end{aligned}$$



Problem Properties

- Nonlinear objective and constraints
- Analytical expression of $f(x)$ and $g(x)$ not available:
  No Derivative Knowledge
- Presence of so-called hidden constranits
- Computation of $f(x)$ and $g(x)$ affected by numerical errors



A difficult Global Optimization problem

Induction Motor Optimal Design

	"optimal" design:	(initial design:)
Stator inner diameter :	$x_1 = 129.94mm$	$(126.6mm)$
Stator outer diameter :	$x_2 = 220mm$	$(200mm)$
Stator teeth width :	$x_3 = 4.53mm$	$(5.5mm)$
Stator slot height :	$x_4 = 19mm$	$(17.5mm)$
Stator wire size :	$x_5 = 2.635mm^2$	$(1.573mm^2)$
Air-gap length :	$x_6 = 0.3mm$	$(0.4mm)$
Rotor teeth width :	$x_7 = 3.543mm$	$(4mm)$
Rotor slot height :	$x_8 = 18.5mm$	$(17.8mm)$
Stack length :	$x_9 = 187.1mm$	$(160mm)$

Optimized design

Induction Motor Optimal Design

"optimal" design:	initial design:
Rated Efficiency of 91.9%	Rated Efficiency of 88.38
Real Measured Efficiency 90.2%	**Real Measured Efficiency 84.2%**

Associazione Nazionale Industrie Elettromeccaniche

il parco motori nazionale relativo alla taglia da 7.5 kW - 4 poli
si aggira intorno ai 30000 motori
(per usi industriali: nastri trasportatori, ventilatori,…)

l'uso dei motori ottimizzati implicherebbe un risparmio annuo di
35 GWh/anno pari a circa 3.5 Milioni di €/anno