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Hamburg

Zonal Electro-Hydraulic Power Generation in Commercial Aircraft



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Nomenclature

Symbols

Latin Symbols

Symbol	Unit	Description
c_p	[J/(kg K)]	Thermal Capacity (at constant pressure)
e	[–]	Error
d	[m]	(Inner) Diameter (Pipe)
d	[–]	Disturbance
f	[Hz]	Frequency
h	[m]	Gap Height (Pump Clearance)
h	[m ² /s ²]	Specific Enthalpy
i	[A]	Current
$k_{f,\Delta P}$	[Nm/bar]	Pressure Dependent Friction Coefficient
$k_{f,\omega}$	[Nm/(rad/s)]	Speed Dependent Leakage Coefficient
$k_{Fe,1}$	[W/(rad/s)]	Iron Losses Coefficient for ω
$k_{Fe,2}$	[W/(rad/s) ²]	Iron Losses Coefficient for ω^2
$k_{Fe,3}$	[W/(rad/s A)]	Iron Losses Coefficient for $\omega \cdot i_q$
$k_{le,p}$	[(l/min)/bar]	Pressure Dependent Leakage Coefficient
$k_{le,\omega}$	[(l/min)/(rad/s)]	Speed Dependent Leakage Coefficient
$k_{le,lam,1}$	[(l/min)/(rad/s)]	Laminar Leakage Coefficient Gap Type 1
$k_{le,lam,2}$	[(l/min)/(rad/s)]	Laminar Leakage Coefficient Gap Type 2
$k_{p,h}$	[m/bar]	Gap Height Pressure Coefficient
k_T	[Nm/A]	Torque Constant
l	[m]	Length (Pipe)
l	[m]	Lever Arm (Actuator)
m	[kg]	Mass
n	[–]	Noise
n	[1/min]	(Pump) Speed

Symbol	Unit	Description
p	[bar]	Pressure
r	[-]	Reference / Set Point
s	[-]	Complex Frequency Parameter
t	[s]	Time
u	[-]	Control Output
u	[V]	Voltage
v	[m/s]	Velocity/Speed
v	[rad/s]	Virtual (total) Control Output
x	[m]	Position
y	[-]	Control Loop Output
y	[-]	Valve (Spool) Position
A	[m ²]	Area
A	[-]	Upper Bound of Performance Weight
B	[(l/min)/√bar]	Orifice Coefficient (Turbulent)
C_p	[(rad/s)/bar]	Pressure Controller Transfer Function
C_H	[bar/m ³]	Hydraulic Capacity
$C_{H,0}$	[-]	Constant Hinge Moment Derivative
$C_{H,\alpha}$	[1/°]	Hinge Moment Derivative for α
$C_{H,\delta}$	[1/°]	Hinge Moment Derivative for δ
CM	[-]	Control Mode
DP	[-]	Default Pump
E_{fl}	[Pa]	Bulk Modulus (Fluid)
ER	[-]	EMP Ready (Operation)
F	[N]	Force/Load
F	[-]	Pre-Filter Transfer Function
G	[-]	Transfer Function
GM	[dB]	Gain Margin
H	[km]	Altitude (<i>germ.:</i> Höhe)
H	[kgm ² /s ²]	Enthalpy
I	[-]	Identity Matrix
J	[kgm ²]	Rotary Inertia
$K_{f,fl}$	[m ⁵]	Fluid Friction Coefficient
$K_{f,\Delta p}$	[m ³]	Pressure Dependent Friction Coefficient

Symbol	Unit	Description
$K_{f,\eta}$	[kg m ² /s]	Viscous Friction Coefficient
K_I	[-]	Integral (Controller) Gain
K_p	[-]	Proportional (Controller) Gain
$K_{le,comp}$	[1/bar]	Compression Loss Coefficient
$K_{le,fill}$	[(l/min)/(l/min) ^{1.8}]	Filling Loss Coefficient
$K_{le,lam}$	[(l/min) s/(bar m ²)]	Laminar Pump Leakage Coefficient
$K_{le,turb}$	[(l/min)/√bar]	Turbulent Pump Leakage Coefficient
L	[H]	Inductance
L	[-]	Loopgain
L	[dB(A)]	Sound Level
M	[-]	Lower Bound of Performance Weight
M	[-]	Known Part of the Uncertain System
M_H	[Nm]	Hinge Moment
Nu	[-]	Nußelt Number
P	[W]	Power
P	[-]	Plant Transfer Function
PM	[°]	Phase Margin
P_d	[bar/(l/min)]	Disturbance Model Transfer Function
P	[1/FH]	(Failure) Probability
P	[W]	Power
Q	[l/min]	Flow Rate
R	[Ω]	Electric Resistance
Ra	[-]	Rayleigh Number
S	[-]	Overload Factor (Accumulator)
S	[-]	Sensitivity
T	[-]	Complementary Sensitivity
T	[Nm]	Torque (Motor, Pump)
V	[m ³]	Volume
V_{th}	[cm ³]	Theoretic Displacement Volume
V_{MCE}	[-]	Gain of the Inverter
W	[-]	Performance Weight

Greek Symbols

Symbol	Unit	Description
α	[-]	Allocation Factor
α	[W/(m ² K)]	Thermal Heat Exchange Coefficient
β	[1/K]	Thermal Expansion Coefficient
δ	[°]	Deflection / Angular Position (Surface)
δ	[-]	Parametric Uncertainty
η	[-]	Efficiency
ϑ	[°C]	Temperature
κ	[-]	Polytrophic Coefficient
μ	[kg/(m s)]	Dynamic Viscosity
μ	[-]	Structured Singular Value
ν	[m ² /s]	Kinematic Viscosity
ξ	[-]	Degradation Factor (Pump)
ξ	[-]	Scaling Factor (Feedforward)
ρ	[kg/m ³]	Density
σ	[-]	Load Share (Pump)
σ	[-]	Singular Value
τ	[s]	Time Constant
φ	[rad]	Angular Position
ω	[rad/s]	Angular Velocity
Δ	[-]	Difference
Δ	[-]	Perturbation Matrix (Uncertain System)
Φ	[W]	Heat Flow
Ψ	[Wb]	Linked Magnetic Flux

Subscripts

Subscript Description

a,b,c	=	Motor Phases A,B,C
accu	=	Accumulator
air	=	Air
amb	=	Ambient (environmental conditions)
c	=	Command
comp	=	Compression
d	=	Disturbance
d,q	=	Motor d/q-Phases
dyn	=	Dynamic
eff	=	Effective (Flow, Torque)
el	=	Electric
f	=	Friction
fill	=	Filling
fl	=	Fluid
g	=	Gas
hyd	=	Hydraulic
hm	=	Hydro-mechanical
lam	=	Laminar
le	=	Leakage
m	=	Mechanical
max	=	Maximum
min	=	Minimum
p	=	Pressure, Pump
ph	=	Phase
red	=	Applying Mass Reduction Measures
rot	=	Rotary / Rotating Group
sys	=	System
th	=	Theoretical (Displacement, Flow, Torque)
tot	=	Total
turb	=	Turbulent
vol	=	Volumetric

Subscript	Description
w	= Wall
Cu	= Copper
Cool	= Reduced Cooling Power
CoZS	= Combined Zone System
CZS	= Center Zone System
CS	= Controller Sensitivity
CSPd	= Controller Disturbance Sensitivity
CV	= Check Valve
DC	= Direct Current
DS	= Downsizing (EMP)
EHA	= EHA Concept
El	= Elevator
EMP	= Electric Motor-Driven Pump
E/R	= Extension/Retraction (Actuator)
FB	= Feedback
Fe	= Iron
FF	= Feedforward
HM	= Hydraulic Motor
HP	= High Pressure Side
L	= Load (Flow, Force)
LP	= Low Pressure Side
LS	= Load Sensing
MCE	= Motor Control Electronic
MLG	= Main Landing Gear
MPU	= Motor Pump Unit
MW	= Motor Winding
(P)Dec	= (Partly) Decentralized (Architecture)
PFC	= Primary Flight Control
PM	= Permanent Magnet
PMSM	= Permanent Magnet Synchronous Motor
N	= Nominal
R	= Response (Time), Return
RO	= Roll-Off (Controller)

Subscript Description

Rud	=	Rudder
S	=	Surface (Aerodynamic Control)
SPd	=	Disturbance Sensitivity
TAS	=	True Air Speed
TZS	=	Tail Zone System
V	=	Loss (<i>germ.:</i> <i>Verlust</i>)
Δp	=	Differential Pressure
ξ	=	Including Scaling by Factor ξ
ω	=	Angular Velocity
∞	=	Infinite Time / Steady State

Abbreviations

Abb.	Description
AC	= Alternating Current
A/C	= Aircraft
ADCN	= Aircraft Data Communication Network
ADP	= Air Driven Pump
ADGB	= Accessory Driven Gearbox
AFDX	= Aeronautical Full Duplex
AOG	= Aircraft on Ground
CoZS	= Combined Zone System
CPIOM	= Core Processing Input Output Module
CZS	= Center Zone System
DAQ	= Data Acquisition
DC	= Direct Current, Displacement Control
DOC	= Direct Operating Cost
DSV	= Door Selector Valve
EBHA	= Electric Back-up Hydraulic Actuator
EDP	= Engine Driven Pump
eH	= electro-hydraulic

Abb.	Description
EHA	= Electro-hydrostatic Actuator
EHSA	= Electro-hydraulic Servo Actuator
EHSV	= Electro-hydraulic Servo Valve
EMA	= Electro-mechanical Actuator
EMP	= Electric Motor-Driven Pump
E/R	= Extension/Retraction
FAL	= Final Assembly Line
FCC	= Flight Control Computer
FHA	= Functional Hazard Assessment
FM	= Flow Matching
FSVD	= Fixed Speed Variable Displacement
GSV	= Gear Selector Valve
HHEX	= Hydraulic Heat Exchanger
hm	= Hydro-mechanical
HP	= High Pressure
HPP	= Hydraulic Power Package
HPPCM	= HPP Control and Monitoring
HSCM	= Hydraulic System Control Module
HTP	= Horizontal Tail Plane
HVDC	= High Voltage Direct Current
IGP	= Internal Gear Pump
IV	= Isolation Valve
ISA	= International Standard Atmosphere
LGCU	= Landing Gear Control Unit
L/G	= Landing Gear
LH	= Left Hand
LP	= Low Pressure
LS	= Load Sensing
LVDT	= Linear Variable Differential Transformer
MCE	= Motor Control Electronic
MEA	= More Electric Aircraft
MISO	= Multiple Input Single Output
MLG	= Main Landing Gear

Abb.	Description
MMEL	= Master Minimum Equipment List
MPC(A)	= Model Predictive Control (Allocation)
MPU	= Motor Pump Unit
MTBUR	= Mean Time between Unscheduled Removal
NLG	= Nose Landing Gear
NZS	= Nose Zone System
OEI	= One Engine Inoperative
PbW	= Power by Wire
PCU	= Power Control Unit
PFC	= Primary Flight Control
PMSM	= Permanent Magnet Synchronous Motor
PMV	= Pressure Maintaining Valve
POB	= Power Off Brake
PRV	= Pressure Relief Valve
PSSA	= Preliminary System Safety Analysis
PTU	= Power Transfer Unit
PV	= Priority Valve
RAT	= Ram Air Turbine
REU	= Remote Electronic Unit
RH	= Right Hand
RVDT	= Rotary Variable Differential Transformer
SFCC	= Slat Flap Control Computer
SISO	= Single Input Single Output
SV	= Servo Valve
TEFO	= Total Engine Flame Out
THSA	= Trimmable Horizontal Stabilizer Actuator
TZS	= Tail Zone System
VFAC	= Variable Frequency Alternating Current
VSFD	= Variable Speed Fixed Displacement
VSVD	= Variable Speed Variable Displacement
VTP	= Vertical Tail Plane
