Applied Mathematical Modelling 37 (2013) 9829–9845

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

A reliability-based manufacturing process planning method for the components of a complex mechatronic system

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ARTICLE INFO

Article history:
Received 21 May 2012
Received in revised form 3 April 2013
Accepted 24 May 2013
Available online 14 June 2013

Keywords:
Process planning
Reliability analysis
Manufacturing uncertainty
Monte Carlo
Electro-hydraulic servo system
Servo valve

ABSTRACT

Uncertainties in the values of the parameters of a system can originate from the manufacturing tolerances of the system components, which can produce a degree of unreliability in the performance of the system. A systematic framework for realistic reliability assessment of an electro-hydraulic servo system has been presented in this paper with the objective of providing adequate information for the selection of the best manufacturing process for each of the servo valve components. Monte Carlo simulation has been employed to evaluate the effect of these uncertainties of the servo valve parameters on the statistical performance of the system. Possible manufacturing processes have been introduced for each component and the justifiability of using each one has been discussed based on the estimated reliability of the system.

1. Introduction

Selection of a suitable manufacturing process for a component is not generally a straightforward task [1,2]. Many factors and criteria have to be considered at the design stage, such as the dimensions and the general shape of the component, the material to be processed, the number of components that are going to be produced, costs and accessibility of the processes, and the allowed ranges for dimensional tolerances. For the fabrication of some components, several manufacturing processes are often used. The procedure of selecting the most suitable manufacturing process for a component is hence a trade-off among all these factors.

With the proliferation of CAD–CAM tools, significant methods and software tools have been developed to simplify this selection process. Boothroyd et al. [3] were among the first researchers who addressed the integrated material and manufacturing process selection problem. They performed the process selection using production rules and pattern matching. This approach is quite effective; however, it does not either have the capability of weighting of the criteria or making comparisons among the alternative processes. Farris and Knight [4,5] developed a new method by mapping the component geometry and material requirements onto sequences of manufacturing processes and suitable materials. In this method, the geometrical and material constraints of the component are the inputs to the system. The output of the system is a list of practical manufacturing processes and materials appropriate for the component. Based on the difficulty of the process sequences and the agreement of the material specifications with the design requirements, the processes and materials are ranked. Dixon and Poli [6] developed a new method which used a guided iterative searching procedure for the evaluation of material and manufacturing processes. This was a handbook approach in which tables and charts were used for the evaluation and comparison

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0307-904X/$ - see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.apm.2013.05.030

Nomenclature

a	width of spool edges, m, 4e−03
A	area of air gap, m^2
A_5	drain orifice area m^2
A_L	area of the flow between spool and sleeve edges
A_o	orifice area, m^2
$A_{a'}$, $A_{b'}$, $A_{c'}$, and A_d	spool valve restrictions areas, m^2
A_P	piston area, m^2, 7e−04
A_s	spool cross-sectional area, m^2
b	width of sleeve slots, m, 4e−03
B	bulk modulus of oil, Pa, 1.5e09
c	spool radial clearance, m, 2e−06
C_c	contraction coefficient
C_d and C_D	discharge coefficients 0.661
d_f	flapper nozzle diameter, m, 5e−04
d_5	diameter of return orifice, m, 6e−04
d_s	spool diameter m 4.6e−03
f_ϑ	armature damping coefficient, Nms/rad, 0.002
F_j	hydraulic momentum force, N
f_p	piston friction coefficient, Ns/m, 1000
f_s	spool friction coefficient, Ns/m, 3.05
F_s	force acting at the extremity of the feedback spring, N
H	Magneto-motive force per unit length, A/m
i_b	feedback current, A
i_c	control current, A
i_e	torque motor input current, A
J	moment of inertia of rotating part, Nms^2, 5e−07
K_b	load coefficient, N/m, 0
K_{FB}	feedback gain, A/m, 1
K_{Lf}	equivalent flapper seat stiffness, N/m, 1e6
K_i	current-torque gain, Nm/A, 0.559
K_s	stiffness of the feedback spring N/m 900
K_T	stiffness of flexure tube, Nm/rad, 10.68
K_ϑ	rotational angle-torque gain, Nm/rad, 9.45e−04
L	armature length, m, 0.0289
L_f	flapper length, m, 0.009
L_s	length of the feedback spring and flapper, m, 0.03
L_{sp}	Length of spool land, m, 1.5e−02
m_p	piston mass kg 5
m_s	spool mass, kg, 0.2
P_1	pressure in the left side of the flapper valve, Pa
P_2	pressure in the right side of the flapper valve, Pa
P_3	pressure in the flapper valve return chamber, Pa
P_A and P_B	hydraulic cylinder pressures, Pa
P_s	supply pressure, Pa, 1.2e7
P_T	return line pressure, Pa, 0
Q	flow rate, m^3/s
Q_1	flow rate in the left orifice, m^3/s
Q_2	flow rate in the right orifice, m^3/s
Q_3	left flapper nozzle flow rate, m^3/s
Q_4	right flapper nozzle flow rate, m^3/s
Q_5	flapper valve drain flow rate, m^3/s
Q_a, Q_b, Q_c, and Q_d	flow rates through the spool valve restrictions, m^3/s
R_i	resistance to internal leakage, Ns/m^5, 1e20
R_s	flapper seat damping coefficient, Nms/rad, 5000
T	torque of electromagnetic torque motor, Nm
T_F	feedback torque, Nm
T_L	torque due to flapper displacement limiter, Nm
T_P	torque due to the pressure forces, Nm
V_3	volume of the flapper valve return chamber, m^3, 5e−06