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Performance-based optimization of multi-pass face milling operations using Tribes

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Abstract

The paper proposes a new optimization technique based on Tribes for determination of the cutting parameters in multi-pass milling operations such as plain milling and face milling by simultaneously considering multi-pass rough machining and finish machining. The optimum milling parameters are determined by minimizing the *maximum production rate* criterion subject to several practical technological constraints. The cutting model formulated is a nonlinear, constrained programming problem. Experimental results show that the proposed Tribes-based approach is both effective and efficient.

Keywords: Multi-pass milling operations; Computer aided process planning; Tribes; Local search optimization techniques

1. Introduction

The advent of modern computer technology and a new generation of manufacturing equipment, particularly computer numerical control (CNC) machine, have brought enormous changes to the manufacturing sector. In process planning of CNC milling, selecting reasonable milling parameters is necessary to satisfy requirements involving machining economics, quality, and safety. The machining parameters in milling operations consists of cutting speed, radial and axial depths of cut, feed, and number of passes. These machining parameters significantly impact on the cost, productivity, and quality of machined parts.

Multi-pass operations are generally used to machine stocks that cannot be removed in a single pass. Some turning operations such as external step turning and boring, and some of the milling operations, such as face milling and deep shoulder milling in which a significant amount of stock material is removed, are good examples of the operations which are commonly required to be machined using multi-pass operations. Determination of the optimal cutting parameters (cutting conditions) such as the number of passes, depth of cut for each pass, speed, and feed is considered as a crucial stage of multi-pass machining as in the case of all chip removal processes and especially in process planning. The effective optimization of these parameters affects dramatically the cost and production time of machined components as well as the quality of the final products.

Although Taylor [1] recognized that an optimum value for the speed can be achieved by maximizing the material removal rate in a single pass operation, the progress in developing optimization strategies has been very slow. Indeed, there have not been many studies on the optimization of machining conditions in the literature [2,3]. This is mainly due to the complex nature of optimization of machining operations that require the following

- Knowledge of machining (i.e. drilling, turning or milling);
- Empirical equations relating the tool life, forces, power, surface finish, material removal rate, and arbor deflection, etc., to develop realistic constraints;
- Specification of machine tool capabilities (i.e. maximum power or maximum feed available from a machine tool);
- Development of an effective optimization criterion (e.g. maximum production rate, minimum production cost, maximum profit or a combination of these);

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Nomenclature

a_{max}	maximum depth cut for machine tool work piece system
a_{min}	minimum depth cut for machine tool work piece system
a_T	total tangential depth of cut (mm)
a_t	tangential depth of cut (mm)
a_r	radial depth of cut (mm)
b_v, b_z	exponents determined empirically
d_b	milling width (mm)
B_m	correction coefficient of tool life equation
B_t	correction coefficient of tool life equation
B_h	correction coefficient of tool life equation
B_p	correction coefficient of tool life equation
c_a	clearance angle of the tool
C_v	a constant taking into account the influence of all factors that are appearing separately in the tool life formula
C_{zp}	constant of the cutting force equation
d_a	arbor diameter (mm)
D	outer diameter of the cutter (mm)
e	permissible values of arbor deflection (mm)
E	modulus of elasticity of arbor material (kg/mm^2)
E_s	modulus of elasticity of stub arbor material (MPa)
f	feed rate (mm/min)
f_z	feed per tooth (mm/tooth)
F_c	means peripheral cutting force (kg)
F_d	permissible force with regard to arbor deflection (kg)
F_s	permissible force with regard to arbor strength (kg)
I_s	moment of inertia of stub arbor (mm^4)
k_b	permissible bending stress of the arbor material (kg/mm^2)
k_t	permissible torsional stress of the arbor material (kg/mm^2)
l_a	lead (corner) angle of the tool
L	length of cut (mm)
L_a	arbor length between supports (mm)
L_s	length of stub arbor (mm)
N_b	total number of components in the batch
N	spindle speed (rpm)
N_p	number of rough passes (an integer)
P_c	cutting power (kW)
P_m	nominal motor power (kW)
T, T_r, T_s	tool life, expected tool life for rough milling, and expected tool life for finish milling (min)
T_p	machine preparation time per component (min)
T_s	set up time of the machine for a new batch (min)
T_L	loading and unloading time (min)
T_a	process adjusting time and quick return time
T_c	tool changing time per component (min)
T_d	time for changing a dull cutting edge or tool (min)
T_m	machining time (min)
T_{pr}	total production time per component (min)
V	cutting speed (m/min)
V_r, V_s	cutting speeds in rough and finish milling (m/min)
V_{rL}, V_{rU}	lower and upper bound of cutting speed in rough milling (m/min)
V_{sL}, V_{sU}	lower and upper bound of cutting speed in finish milling (m/min)
f_r, f_s	feed rates in rough and finish milling (mm/rev)
f_{rL}, f_{rU}	lower and upper bound of feed rate in rough milling (mm/rev)
f_{sL}, f_{sU}	lower and upper bound of feed rate in rough milling (m/rev)
d_r, d_s	depths of cut for each pass of rough and finish milling (mm)
d_{rL}, d_{rU}	lower and upper bound of depth of cut in rough milling (mm)
d_{sL}, d_{sU}	lower and upper bound of depth of cut in finish milling (mm)
z	number of teeth on the cutter
η	overall efficiency
δ	permissible deflection of stub arbor at the end (mm)
λ_s	cutting inclination angle
SR	maximum allowable surface roughness (mm)
R	nose radius of cutting tool (mm)
F_r, F_s	cutting forces during rough and finish milling (kgf)
F_U	maximum allowable cutting force (kgf)
P_r, P_s	cutting power during rough and finish milling (kW)
P_U	maximum allowable cutting power (kW)
e_v, e_z	exponents determined empirically
r_v, r_z	exponents determined empirically
u_v	exponent determined empirically
u_z	exponent determined empirically
m	exponent determined empirically
n_v, n_z	exponents determined empirically
q, q_v	exponents determined empirically
P	exponent determined empirically

- Knowledge of mathematical and numerical optimization techniques, such as the Simplex method, Search method, Geometric programming and dynamic programming, etc.;
- Knowledge of stochastic optimization techniques, such as the genetic algorithms, simulated annealing, scatter search, particle swarm optimization and tribes, etc.