A NEW COST MODEL FOR HIGH SPEED HARD TURNING OF AISI 4340 STEEL

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy (Engineering)

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JANUARY 2012

ABSTRACT

Technology is developing from grinding to hard turning then to high speed hard turning (HSHT) in which three advanced turning processes are merged together: hard turning, high speed turning and dry turning. Among the advantages of this modern process are final product quality, reduced machining time, and lower machining cost. On the other hand, the high cost of the cutting tools must be minimized. Thus there is clearly a need to study HSHT economically to give the evidence to the industrial sector that this process is worth considering. In order to demonstrate its economic viability, it is of particular importance to develop a cost model to run in optimal conditions based on specified objectives and practical constraints. In this research, a scientific and systematic methodology to design cost model and the optimal cutting conditions is developed. A new procedure was proposed for structuring and developing the cost model. This procedure is a hybrid of different estimating methods supported by statistical and artificial intelligent techniques. In this study; the following parameters are used; cutting speed 175-325 m/min, feed rate 0.075 – 0.125 mm/rev, depth of cut 0.1 – 0.15 mm and negative rake angle from zero to (-12) degree. The work piece material was AISI 4340 hardened to 60 (HRC) and the cutting tool is mixed ceramics (AL_2O_3- TiC) under dry conditions. The experimental works were divided into two different designs; Full Factorial Design (FFD) for three independent variables (cutting speed, feed rate and negative rake angle) and Box-Behnken Design (BBD) in which the depth of cut was also considered. Surface roughness, flank wear length, cutting forces and feeding forces have been measured, and then two different methods have been used in modeling and predicting the measured parameters; BBD and ANN. It is found that the BBD gave the better results with lower deviation. Machining time and tool life were the main drivers of the cost in HSHT process. Machining time has been modeled by dividing the time into three main elements; operation time, non operation time and preparation time. The tool life was predicted by direct monitoring of the flank wear progress. It was found that the statistical approach gave better predicting to use in the cost models. The machining cost was measured by RM/cm^2 and broken down into three main parts; machine cost rate per time (labor, maintenance, material, energy, capital, and renting costs), tooling costs and energy cost then a mathematical relationship relating the cost of a process as a dependent variable to one or more independent variables were derived for three different scenarios; one shift, two shifts and three shifts with 300 working days. By using BBD as one of the RSM collections, new models for surface roughness, machine cost rate, tooling cost and energy cost have been developed using only four inputs variables. Two different optimization methods; Desirability function (DF) and genetic algorithm (GA), have been applied to obtain the minimum values of the total machining cost and surface roughness. The results show that the best values in the boundary design that can achieve the minimum roughness (0.31 μm) with machining cost 0.595 RM/cm^3.

خلاصة البحث

تكنولوجيا قطع المعادن تغيرت من التجليغ الى الخراطه السريعه للمواد الصلبه (HSHT) حيث يتم دمج ثلاثه عمليات خراطه متقدمه في عمليه واحده: الخراطه عاليه السرع، الخراطه صلبه، والخراطه الجافه. من بين مزايا هذه العملية الحديثة هوجودة المنتج النهائي، تقليل الوقت، وانخفاض التكلفة. من ناحية أخرى فان كلفه ادوات القطع سترتفع كنتيجه لارتفاع معدل التاكل في عدد القطع، وبالتالي فمن الواضح أن هناك حاجة ماسه لدراسة HSHT اقتصاديا لإعطاء الأدلة للقطاع الصناعي أن هذه العملية تستحق النظر. ومن أجل إثبات جدواه الاقتصادية ، فإنه من الأهمية ان يكون هناك نموذج للتنبؤ بتكاليف التشغيل في الظروف المثلى على أساس الأهداف المحددة والقيود العملية. في هذا البحث، استخدمت منهجية علمية لتصميم نموذج التكلفة وتحديد الظروف المثلى للقطع. واقترحت إجراءات جديدة لتنظيم وتطوير نموذج التكلفة. هذا الإجراء هو مزيج من الأساليب المختلفة لتقدير الكلفه مدعومة بتقنيات الذكاء الاصطناعي والإحصائي. في هذه الدراسة، وسيتم تغطية الحدود التالية؛ سرعة القطع 175-325 متر / دقيقة، ومعدل تغذية 0.075 -0.125 مم / دوره، وعمق قطع 0.1-0.15 ملم وزاوية سلبية من صفر إلى (-12) درجة. الماده المستخدمه في التجارب العمليه هي (AISI 4340) مصلده إلى 60 (HRC) وأداة قطع السيراميك هو ($Tic- Al_2O_3$) في ظل ظروف قطع جاف. التجارب كانت بتصميمين: Full Factorial Design (FFD) و Box Behnken Design (BBD) تم من خلال التجارب قياس كلا من خشونة السطح، وطول التاكل، قوى القطع و قوى التغذيه، ومن ثم تم استخدام طريقتين مختلفتين في النمذجة والتنبؤ BBD وANN. وجد أن BBD أعطى نتائج أفضل مع انخفاض نسبه الخطاء. وكان عمر اداه القطع وزمن القطع هما العوامل الاساسيه في قياده الكلفه. وقد تم عمل ونمذجه زمن القطع بتقسيم الوقت إلى ثلاثة عناصر رئيسية هي؛ الوقت الإنتاجي، والوقت غير منتج، والوقت اللازم لإعداد. وتم حساب وعمل نمذجه لقياس عمر اداه القطع استنادا على معدل التاكل في عده القطع. وقد تبين أن النهج الإحصائي يعطي تنبؤ على نحو أفضل لاستخدامها في نماذج التكلفة. وتم قياس كلفة القطع بحساب كلفه ازاله سنتميتر مكعب من المواد. اجزاء الكلفه تم تقسيمها الى ثلاثه اجزاء رئيسيه ، معدل كلف التشغيل(العمل والصيانة والمواد والطاقة ورأس المال وتكاليف استئجار)، وكلف ادوات القطع وتكلفة الطاقة ثم وجود علاقة رياضية تربط تكلفة عملية كمتغير يعتمد على واحد أو أكثر من المتغيرات المستقلة و استخدمت ثلاثة سيناريوهات مختلفة استنادا على عدد وجبات العمل فتره عمل واحده، فترتي عمل وثلاث فترات خلال اليوم الواحد مع 300 أيام عمل في السنه. باستخدام BBD باعتبارها واحدة من مجموعات RSM، طورت نماذج جديدة للتنبؤ لكل من :خشونة السطح، معدل كلف التشغيل، وكلف ادوات القطع وتكلفة الطاقة باستخدام أربعة فقط من المتغبرات:سرعه القطع،معدل التغذيه،عمق القطع وزاويه القطع وقد طبقت طريقتين لتعظيم النماذج للحصول على قيم الحد الأدنى من التكلفة الإجمالية بالقطع والحد الادنى من خشونة السطح باستخدام تقنيتين مختلفتين الاولى احصائيه والثانيه مستنده على الذكاء الصناعي:Desirability Function(DF) كواحدة من التقنيات الإحصائية والخوارزمية الجينية (GA) باعتبارها واحدة من تقنيات الذكاء الصناعي وأظهرت النتائج أن أفضل القيم في تصميم الحدود التي يمكن أن تحقق الحد الأدنى من خشونة (0.31 ميكرون) وتكلفة الآلات 0،595 RM / سم ³.

APPROVAL PAGE

The thesis of Muataz Hazza Al Hazza has been approved by the following:

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muataz Hazza Faizi Al Hazza

Signature……………………………. Date ………………………..

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……………………………. ………………..

Signature Date

Dedicated to my dearest father who died before my PhD

Also dedicated to

My mother,
My dearest wife
My daughter Zubaidah
My son Mohamed
My daughter Hajer

ACKNOWLEDGMENTS

In the name of Allah, the most Compassionate, the most merciful. I would like to express my utmost thankfulness to Allah subhanahu talaa for the shower of His blessings and mercies that I have successfully completed my research work. In practical, sincere appreciation and thanks to my respected supervisor Prof. Dr. Erry Y. T. Adesta for his relentless guidance, patience and support throughout the research. I would like also to thank Dr Wan Ahmad Yusmawiza Wan Yusoff for his supporting guidance as Co- supervisor

I also express a note of thanks to all members of the research group and the technicians of different labs of manufacturing and materials engineering department for their supports and contribution to me. Special thanks to the center of postgraduate studies (CPS), and other related departments in International Islamic University Malaysia for their kind cooperation and assistance.

My wife Azhar Ibraheem deserves my admiration, love and thanks for her unending support and sacrifice. My love goes to my daughters Zubaidah and Hajir and My son Mohmaed. I want to dedicate this work to my parents, wife, daughters and son.

Last but not least, I feel profuse gratitude to my entire family. They have always encouraged and supported me during my whole life. Their hearts and souls have enlightened my way to my righteousness and being a devoted and committed Muslim.

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ABC	Activity Based Costing
AEUI	Annual Area Use Index
AISI	American Iron and Steel Institute
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
BBD	Box-Behnken Design
BHN	
BUE	Built Up Edge
CAD	Computer Aided design
CAM	Computer Aided manufacturing
CBR	Case-Based Reasoning
CBN	Cubic Boron Nitride
CCD	Central Composite Design
CEF	Cost Estimation Formula
CER	Cost Estimation Relationships
CNC	Computer Numerical Control
DF	Desirability Function
DOE	Design Of Expert
FCC	Face Centered Cube
FFD	Full Factorial Design
GA	Genetic Algorithm
GP	Geometric Programming

IMC	Integrated Measurement & Control
ISO	International Organization Standardization
HRC	Rockwell Hardness
HSHT	High Speed Hard Turning
NN	Neural Network
PCBN	Poly Cubic Boron Nitride
RSM	Response Surface Methodology
RCGA	Real Coded Genetic Algorithms
SS	Stainless Steel

LIST OF SYMBOLS

A_t	Gross area of the machine occupation
C_L	Operator cost per hour (Rm/hour)
C_A	Cost rental for one meter cubic
C_{rate}	Machine cost rate (Rm/cm³)
C_{labour}	Labor cost (Rm/ min)
C_{main}	Maintenance cost (Rm/min)
$C_{building}$	Building cost (Rm/min)
$C_{energy\,(f)}$	Fixed energy cost (Rm/min)
$C_{capital}$	Capital cost (Rm/min)
C_{Tc}	Tooling cost for one pass
C_T	Tool cost per one edge (Rm)
C_{E1}	Energy cost when the machine in route of cutting but not in touch
C_{E2}	Energy cost when the cutting tool in touch with work piece
$\cos\varnothing$	Power factor
α	degagement angle (degree)
d	Depth of cut (mm)
D_i	The initial diameter of the work piece before each pass
E_c	Energy tariff (Rm /Kwh)
E_1	Energy during cutting route without touch the work piece (kw)
E_2	Energy during cutting(kw)
e_z	Engagement distance on Z-axis
e_x	Degagement distance on X-axis
f	Feed rate (mm/rev)
h_L	Tool holder life (edge)
i	Interest rate
i_c	Insert cost (Rm)
k_m	Maintenance and reparation supplement (3%)
L_c	Cost of labor (Rm/hour)
L	Tool life (min)
l	Work piece length
M_p	Machine tool price (Rm)
n_L	Number of operators
n_i	Number of insert edges
n_{tool}	Number of tool posts in the turret

P_1	Initial position of the turret
P_2	Position of the used tool in the turret
P_h	Tool holder price (Rm)
R	Rake angle (degree)
r	Work piece radius (mm)
r_t	nose radius for the cutting tool (mm)
r_w	Wear rate progress (mm/min)
r_{speed}	Rotation speed of the turret (rev/min)
T_e	Cutting temperature (C^o)
T_p	Machine tool life (year)
T_{prod}	Productive time(min)
T_{prep}	Preparation time (min)
T_{set}	Setting time (min)
T_{prog}	Programming time (min)
T_{ch}	Tool changing time (min)
$T_{alowance}$	Total allowance (min)
$T_{Mallowance}$	Machine allowance (min)
$T_{Oallowance}$	Operator allowance (min)
Δt	Change of time
T_{it}	Time of insert in touch with work piece. (min)
VB	Flank wear length
ΔVB	Flank wear change during time
V_c	Cutting speed (m/min)/
V_f	Feeding speed (mm/min)
V_o	Rapid speed (m/min)
W_h	Number of working hours per year

CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND OF THE STUDY

The intense competition among manufacturers and the demand for shorter times to market are driving innovative approaches in creating faster production process (Layer, Brinke, Houten, Kals, and Haasis, 2002). Ideally, all of these approaches should be followed and justified by economic study. One of the most effective tools for economic study is by developing a cost model. Developing a cost model for a new technology is the most important step while at the same time is also the most difficult due to the limitation of accurate information for such a new technology. On the other hand, it is an effective tool for decreasing the cost of uncertainty, which is usually associated with new technologies. It will provide the manufacturers and the decision-makers alike with accurate cost information to assist them for making the decisions.

One of the new approaches in creating faster machining process in material removal technology is by applying High Speed Hard Turning (HSHT). It is a process of integrating three advanced turning processes together: hard turning, high speed turning and dry turning. HSHT has emerged as an advantageous machining process for cutting hardened materials in recent years. Among the advantages of this modern turning process are final product quality, reduced machining time, and lower machining cost (Mamalis, Kundrak, Markopoulos, and Manolakos, 2008).

From the discussion above there is clearly a need to study the impact of HSHT to look into the economic value of this process. In the current literature, little research is looking at the economic aspects of high speed hard turning in comprehensive