Surface Roughness Prediction in Deep Drilling by Fuzzy Expert System

Sivarao, Castilo, Tajul

***Abstract*— Numerous operations in manufacturing industries require a length-to-diameter ratio greater than 5 times tool diameter. These types of operations, known as deep drilling, normally need the use of special tools and devices. The deep drilling is a process of high complexity due to its special difficulties such as cutting in a closed and limited space, high cutting temperature and the difficulty of chip formation and removal. Such conditions involve the chip formation and the flow difficulty, the tool overhang length, the surface quality and the hole geometric and form tolerances. This work presents an experimental and an analysis of the performance of carbide drill geometry in drilling of GG25 gray cast iron. The experiments have been carried out in line of production and laboratory, using tungsten carbide drills with straight flutes and internal cutting fluid. The aim of this experimental and analytical research is to identify the parameters which enable the prediction of surface roughness in drilling by integrating expert system. Fuzzy expert system were used to analyze the best fit model in predicting the quality of the deep drilled holes. With the results obtained in this work it was possible to acquire a major knowledge on the deep drilling process of gray cast iron, which allow improvements in the production of pieces in industrial scale.**

***Index Terms*—Fuzzy expert system, deep drilling, gray cast iron, surface roughness, Ra Prediction.**

I. Introduction

The drilling process is nowadays an operation with huge numbers of applications in the industry. Although the most holes are short, in a significant parcel the relation length/diameter is greater than five. This kind of process, named deep drilling, is a complex operation because of the difficult chip formation and flow, the tool overhang length, the surface quality and the demanded hole geometric and form tolerances. Thus the deep drilling needs special conditions to be made, such as the adequate tools and the coolant fluid injection under pressure in the cutting area [1],[2],[3].

Ir. Sivarao is a Professional Engineer (P.Eng.) in the field of Mechanical Engineering who currently serves as a lecturer and researcher in the Faculty of Manufacturing engineering, Universiti Teknikal Malaysia Melaka (UTeM). He is the corresponding author. (phone: 6063316505, Fax: 6063316411 & email: sivarao@utem.edu.my or kpe_siva@yahoo.com).

Willian Jefferson Gonzalez Castillo is a research fellow in Federal University of Santa Catarina, Mechanical Engineering Department, Brasil. He specializes in machining, especially deep drilling of cast irons (email castilo@lmp.ufsc.br)

Tajul Arifin Abdullah is a lecturer and researcher at Faculty of Manufacturing Engineering. His area of expertise is in product design quality evaluation (email: tajul@utem.edu.my).

In some cases, the deep drilling can also be executed by conventional helical drills, using interruption cycles in the process for chip removal [4],[5],[6]. The deep drilling is widely used in manufacturing process of mechanical components as crankshafts, connecting rods, hydraulic cylinders, turbine parts, heat exchangers, etc. In a global industry which is necessary care with quality rigid norms, a machining process inside of a production line must conjugate the quality of the machining parts and the tool life, in short time of manufacture.

This scientific research aims to analyze the performance of carbide drill tool geometry in drilling of GG25 gray cast iron by integrating Sugeno-Fuzzy Expert System. Moreover, this research has for objective to generate information about the disturbing factors in the process, which are directly related with the machine-tool, the workpiece part, the tool and the cutting parameters. With the results obtained in this work it was possible to acquire a major knowledge on the deep drilling process of gray cast iron, which allow improvements in the production of pieces in industrial scale. To know the drilled surface quality, it is necessary to employ theoretical models making it feasible to do predictions in function of response parameters. The measurement and stochastic modeling of speed, torque and thrust force in drilling has been the main interest of many researchers as it was the best method of indirect tool wear sensing [7].

The resurgence of interest in Expert System over the past few decades has opened many new avenues in its applications. Expert System leads to greater generality and better rapport with reality. It is driven by the need for methods of analysis and design, which can come to grips with the pervasive imprecision of the real world and exploit the tolerance for imprecision to achieve tractability, robustness and low cost solution [8]. Fuzzy modeling is based on the idea to find a set of local input-output relations describing a process. So, the method of Fuzzy modeling can express a non-linear process better that any ordinary method. As more knowledge about the system is accumulated, the uncertainty diminishes the need for the Fuzzy Logic treatment and it can revert to a deterministic or statistical one.

The aim of this experimental and analytical work is to identify suitable parameters, the monitoring of which enable the prediction of surface finish for drilled holes by an Expert System namely Fuzzy Logic. It has its own ability in determining the output and decision making in tool condition monitoring which determines and maintain the quality of drilled surface to its highest standard of the product. Finally, the entire experimental work of quality holes are to be validated by the Expert System within the range of experimental values.

II. Experimental Procedures

The specimens used were turned and faced of cylindrical pieces in gray cast iron GG25, with 72 mm length and 16 mm diameter. The specimen hardness value was 260 HB, with a 10 HB standard deviation. The feed force acquisitions were made in a three axis numerical command milling machine, Romi Polaris F400. This machine has a vertical arbor with 6.000 rpm highest rotation. High pressure coolant fluid system has been installed on this machine and the work pressure was set to 25 bar. The wear tests were developed in a drilling horizontal machine commanded by CLP, whose maxim spindle rotation is 5.000 rpm. This machine possesses a rotating tool configuration and the workpiece is submitted to a pneumatic clamping system.

In this work it was used a set of nine carbide drills, with 9.5 mm diameter with a modified sharpening, classified as X geometry. Fig. 1 shows the drill geometry characteristics. This carbide tools are K20 class with straight flutes with internal refrigeration orifices.

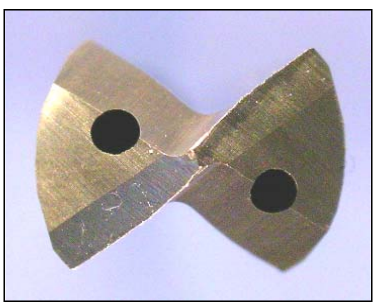

Fig. 1. Geometry X drill tool with orifices

Table 1: Modified drill tool specifications

Geometry	X
Point angle σ [°]	120
Clearance angle α [°]	12
Chisel edge angle ψ [°]	68
Chisel edge length [mm]	0.64
Width guide [mm]	0.70
Diameter Ø [mm]	9.55

Table 1 describes the main characteristics of the drill geometry. The tools present different sharpened geometry with variations related to the point angle, clearance angle, chisel edge angle, chisel edge length and width guide. The cutting parameters were based in the normalized numbers R20 series, extracted from the DIN 323 standard.

The cutting parameters are shown at Table 2.

Table 2: Cutting conditions

Condition	Speed [m/min]	feed [mm/rev]
1	112	0.08
2	125	0.08
3	140	0.08

III. Fuzzy System

Fuzzy logic has a lot of applications in the real world. Basically the system will accept the input or some inputs and then pass the inputs to a process called fuzzification. In the fuzzification process, the input data (can be digital, precise/imprecise) will undergo some translation into linguistic quantity such as low, medium, high of physical properties. The translated data will be sent to an inference mechanism that will apply the predefined rules. The inference mechanism will generate the output in linguistic form. The linguistic output will go through defuzzification process to be in numerical form (the normal data form). Defuzzification is defined as the conversion of a fuzzy quantity represented by a membership function to precise or crisp quantity [9, 10].

Fuzzy modeling and approximation are the most interesting fields where fuzzy theory can be effectively applied. As far as modeling and approximation is concerned, one can say that the main interest is towards its applications. When we intend to apply fuzzy modeling and approximation to an industrial process, one of the key problems to be solved is to find fuzzy rules.

IV. Sugeno-Type Fuzzy Inference

The most commonly known or used fuzzy inference methodology is Mamdani. But, this paper discuss the so-called Sugeno, or Takagi-Sugeno-Kang, method of fuzzy inference. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant but can be excellently suited for modeling nonlinear systems by interpolating between multiple linear models. A typical rule in a Sugeno fuzzy model has the form, If;

Input 1 = x, Input 2 = y, then output is $z = ax + by + c$

For a zero-order Sugeno model, The output level z is a constant, ($a=b=0$). The output level z_i of each rule is weighted by the firing strength w_i of the rule. For example, for an AND rule with Input 1 = x and Input 2 = y, the firing strength is w_i = And Method [F1(x), F2(y)] where F1, F2 are the membership functions for Inputs 1 and 2. The final output of the system is the weighted average of all rule outputs, computed as shown by equation (1) and the Sugeno rule operates as shown in Fig. 2.

$$\text{Final Output} = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \quad (1)$$

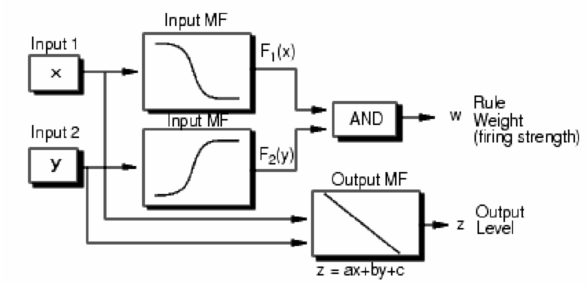

Fig. 2. Sugeno final output rule

Due to the linear dependence of each rule on the input variables of the system, Sugeno method is ideal for acting as an interpolating supervisor of multiple linear controllers that are to be applied, respectively, to different operating conditions of a dynamic nonlinear system. A Sugeno fuzzy inference system is extremely well suited to the task of smoothly interpolating the linear gains that would be applied across the input space; it is a natural and efficient gain scheduler. Similarly, a Sugeno system is suited for modeling nonlinear systems by interpolating between multiple linear models [3]. The plot of membership function and input-output variables fed into the Fuzzy Inference System (FIS) is shown in Fig. 3, with Fine, Medium and Course limits.

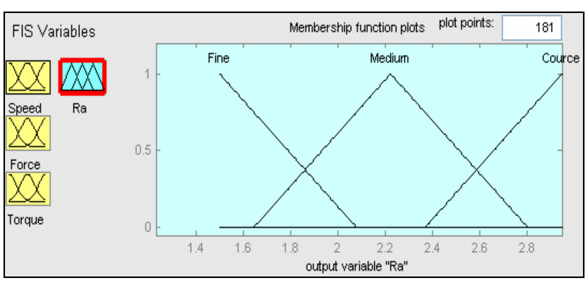

Fig. 3. Membership function of Sugeno-Fuzzy

Upon developing the membership function, precise rules have been fed into the system relating the FIS input-output variables. Each of these rules plays an important role in generating the fuzzy logic controller model and the accuracy of the numerical output. Few rules fed to the FIS based on theoretical study and experience to obtain the higher accuracy output. The rules fed are shown in Fig. 4.

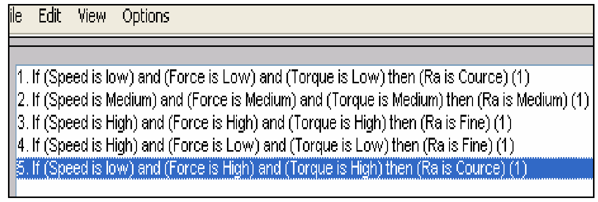

Fig. 4. Five rules applied to Sugeno fuzzy system

Upon the rules determination, the fuzzy logic controller simulates the FIS variables with respective fed rules and modeling of the controller tool box will take place. The model controller of each rule fed to system has been developed by the system as shown in Fig. 5.

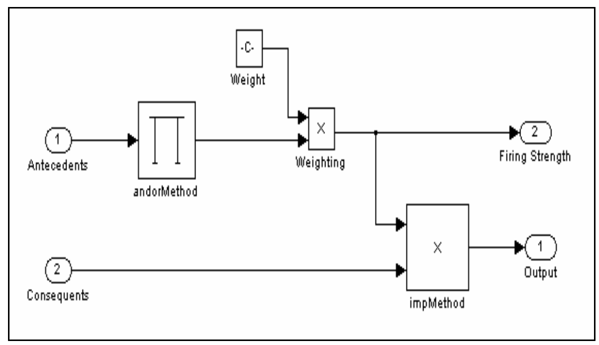

Fig. 5. Controller tool box for each rule

V. Result and Discussion

The roughness dispersions resulted in the three speed conditions had kept in low levels. This means that did not have great differences between the measurements carried through for each body of test (enter and exit hole). Fig. 6 shows the sample of the worked material with X geometry drill tool. For all the machined holes with X geometry drill tool at with condition 1, 2 & 3, it is perceived that all the conditions resulted the roughness to be within 1.0 and 3.0 µm which falls between the range of recommended values.

Fig. 6. Worked sample with X geometry drill tool

This paper established a comparison between holes drilled with X geometry drill tools, where the force increases higher than 30% between the new and the end of tool-life. This increase shows the effects of a deficient cut carried through by tools that normally present a significant wear in its end of tool-life. The machined surface obtained by all the tools tested were considered satisfactory, below the limit of Ra = 5 µm used in this work. The Ra roughness values in all machining conditions tested was within the range of 1.0 and 3.0 µm.

The geometry tested witnessed a good stability on parameters in the machining condition 1, 2 and 3. The qualitative evaluation showed that the results of the machined holes were generally good with moderate surface marks, breakings on the edge and showed a good machining surface roughness. This geometry tool which has chamfered noses showed the best performance and stability of results in the machining of gray cast iron GG25 with the feed and speed tested. Chamfered noses contribute for a good finishing and prevent breakings in the edge of the holes.

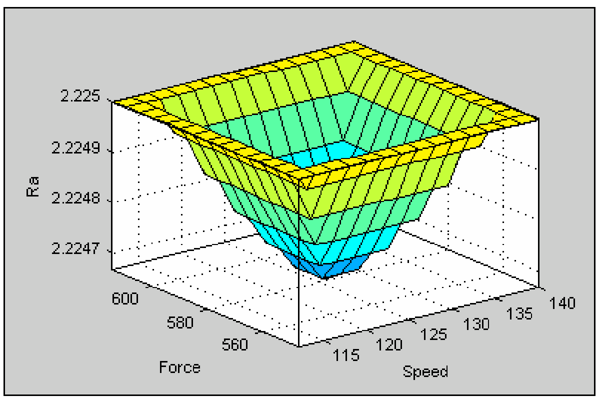

Fig. 7. Sugeno-Fuzzy model-GG25 deep drilling

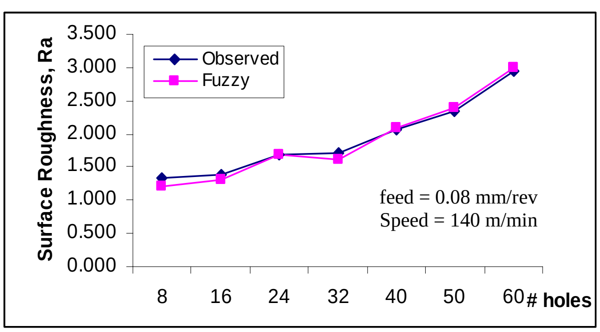

Fig. 8. Result validation for condition no. 1

Fig. 7 is the Sugeno-Fuzzy based surface model showing an excellent relationship between the sets of input variables; speed & force in the relationship of Surface roughness, Ra. The membership function and the rules fed to the system correlates well with the model and matches closely with the observed results within the range of experimental values.

The comparative plots of observed and predictions of expert system are shown in Fig. 8, Fig. 9 & Fig. 10.

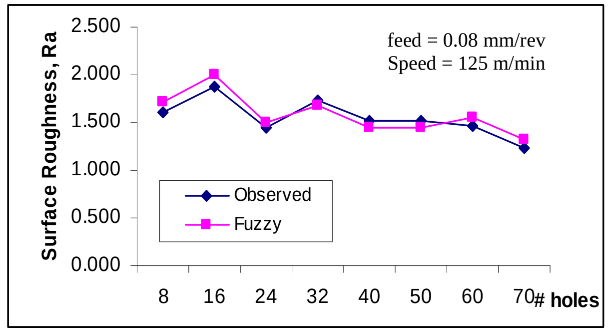

Fig. 9. Result validation for condition no. 2

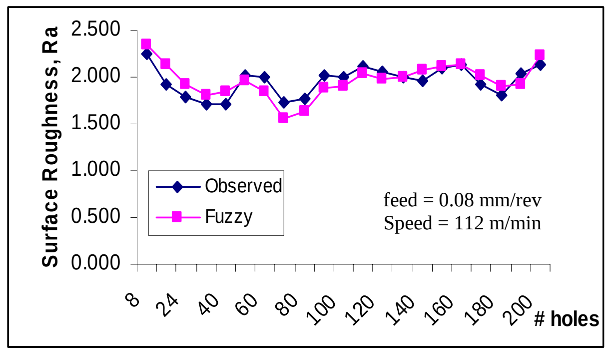

Fig. 10. Result validation for condition no. 3

VI. Conclusions

This paper established the comparison between holes drilled with different combinations of machining parameters, where a force increase higher than 30% between the new and the end of tool-life condition. This increase shows the effects of a deficient cut carried through by tools that normally present a significant wear in its end of tool-life. The machined surface obtained by all geometry tools tested was considered satisfactory, below the limit of Ra = 5 µm used in this work. The Ra roughness values in all machining conditions tested was inside the range of 1.0 and 3.0 µm.

The surface roughness comparative output of the Fuzzy expert system against the observed values are clearly indicating the good agreement of these two outputs. It has been studied that, Fuzzy has the ability of predicting the future (forecasting) based on the membership function of the input and output variables, limits and rules fed and it is strongly recommended for handling this kind of research and further result validation.

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BIOGRAPHIES

Ir. Sivarao is a professional engineer in the field of mechanical engineering and he currently serves Universiti Teknikal Malaysia Melaka as a researcher. He is an active researcher in the field of manufacturing engineering, specializing in precision machining and artificial intelligence. He has published his findings in eight international journals and more than 50 conference proceedings. He has also won eight medals in various innovative product design competitions including the one held in Geneva year 2007.He is also an active reviewer for Journal of Engineering Manufacturer (UK), Journal of Mechanical Engineering Science (UK), IJMPT (special issue) and few International Conferences. To date he has been awarded few research grants totaling up to 200K and he has a product patented and commercialized. He is also an active member of few professional associations including Board of Engineers Malaysia, Academy of Malaysian SMEs, The Institute of Engineers Malaysia, Malaysian Invention and Design Society and International Association of Engineers, UK.

Willian Jefferson Gonzalez Castillo is a research fellow in Federal University of Santa Catarina, Mechanical Engineering Department, Brasil. He specializes in machining, especially deep drilling of cast metals. He has published 10s of international journals and about 50 conference proceedings. He is an active researcher who solves many industry problems related to cutting tools and also quality evaluations.

Tajul is the head of manufacturing design department at Universiti Teknikal Malaysia Melaka (UTeM). He is active in product design quality evaluation and improvement.