## Prediction system of magnetic abrasive finishing (maf)



Prediction System of Magnetic Abrasive Finishing (MAF) On the Internal Surface of Cylindrical Tube Ching-Lien Hung1+, Wei-Liang Ku2, Lieh-Dai Yang3 Submitted to Materials and Manufacturing Processes March, 2010 This paper has not been published elsewhere nor has it been submitted for publication elsewhere. 1+, 3 Department of Industrial Engineering and Management, Nan Kai Universtiy of Technology, Nan Tou, Taiwan, R. O. C. 2 Department of Information Management, Nan Kai University of Technology, Nan Tou, Taiwan, R. O. C. +Corresponding author 1 Abstract This study mainly used the way of the magnetic abrasive finishing (MAF) to explore the cylindrical tube of stainless steel SUS304 related to the processing characteristic and the prediction system. The self-make adjustable electricity polishing mechanism was assembled on the magnetic abrasive machine. The magnetic abrasive which was consisted of the sintered iron and Aluminum Oxide powder filled in the cylindrical stainless steel tube. Magnetic abrasive in the electromagnetic field was absorbed on the cylindrical tube to become flexible magnetic brush. It could generate adjustable pressure on the work piece surface when the magnetic brush is grinding, it could make the workpiece face polished to the mirror surface degree. This experiment used the non-magnetic stainless steel SUS304, following experimental design to conduct the experiments and to explore the effects of various parameters such as rotational speed, vibration frequency, current strength, abrasive, etc., to the surface finish characteristics. After statistical analysis, ANOVA was obtained, and then surface finish prediction system was constructed based on the significant parameters, and the system precision was about 97%. The system will be further to develop an adaptive control model for

MAF in a real fashion. Key words: Magnetic abrasive polishing; flexible https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishingmaf/

magnetic brush, experimental design, prediction model, surface finish. 1. Introduction The rapid development of the semiconductor, biotechnology, and optical electronic industries has increased the importance of geometrical precision and part surface quality. Finishing is regularly applied to parts to obtain precise surfaces. Hence, numerous finishing techniques have been applied for finishing parts to obtain parts with high quality. These techniques include chemical mechanical polishing (CMP), electrical polishing (EP), and many others. However, both CMP and EP suffer from the formation of pollutants during its operations, and also yield surfaces with limited quality. Consequently, researchers in the industry and academics have attempted to develop a better means of obtaining a high-precision surface, with low cost, high efficiency, easy operations and low environmental pollution. Following recent technological developments, stainless steel materials with characteristics of anti-oxidizing, anti-corrosive, and shiny surface have been applied in electronic, biochemical and medical instrumentation equipments. The surface of stainless steel parts must be extremely smooth to prevent pollution. Optimally, the surface finish can reach a level in that it looks like a mirror. A smooth stainless steel surface not only improves the parts quality but it also prevents rusting and staining of the parts surface. Finished parts can prevent the occurrence of the following situations: powder particles remaining on the part surfaces, contact between parts and the stainless steel surface, rough surfaces residing with oil dusk or food particles, and stainless steel burr of processed parts falling off when two parts contact each other. Stainless steel is a soft, tough, and a difficult finishing material. Thin plate stainless steel that uses traditional processes is not easy to achieve a good surface 2 finish. Hence, manual finishing was usually applied to achieve https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishingmaf/

a surface finish that looks like a mirror. However, it is very time consuming to achieve a good surface finish using manual finishing techniques for stainless container steel surfaces. To resolve the above problems, magnetic abrasive finishing (MAF) was recently created. MAF involves using a permanent magnet or an electronic magnet to generate a magnetic field,

abrasive finishing (MAF) was recently created. MAF involves using a permanent magnet or an electronic magnet to generate a magnetic field, and the magnetic abrasives are formed as a flexible magnetic brush for pressing the workpiece [1, 2]. Thus, the magnetic brush becomes a finishing tool, and the magnetic abrasives of the magnetic brush stick to the workpiece during the finishing. Moreover, the frictional force generated by the abrasive finishing can remove particles of free-form surface. The procedure is repeated until a desired surface finish is attained. When a permanent magnet was installed on the topside of the workpiece, any uneven or concave areas on the part could be finished [3-5]. Moreover, when the magnetic pole was installed inside or outside of the part, the internal and external pipes could also be finished [6]. Therefore, MAF is a multi-function precise finishing method. Workpiece materials can be magnetic (such as steel) or non-magnetic (such as ceramic), and the material removal weight can also be adjusted based on the size of the magnetic abrasives. The finishing pressure is controlled via the magnetic field, so MAF is used for micro-pressure finishing [7, 8]. Thus, the MAF method achieved a highly efficient way of obtaining a good surface finish. This study attempts to develop a surface finishing technique for stainless steel, with the aim of analyzing the effects of different parameters and constructing the prediction system for the development of a further adaptive control system. Secondly, this investigation seeks to enhance surface finish of parts in order to meet the customer requirements. 2. Magnetic abrasive finishing 2. 1 Fundamental https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishingmaf/

principle Magnetic abrasive finishing (MAF) of free-form surfaces involves filling the gap between the circular magnetic pole and the workpiece with the magnetic abrasives. The magnetic abrasives consist of sintered pure iron powder (99. 9% Fe) and Al2O3. The end face of the magnetic pole absorbs the magnetic abrasives and forms a closed-loop magnetic field with the workpiece holder. The magnetic abrasives are generated in a non-uniformly magnetic field; in which the abrasives will join each other and follow the direction of the magnetic force to form a flexible magnetic brush. Refer to Figure 2-1 to see how the magnetic brush acted on the free-form surface. The magnetic force lines generated power to apply pressure from the magnetic abrasives to the workpiece, and the magnetic brush became a tool for finishing the workpiece. Moreover, the magnetic abrasives in the magnetic brush stick to the workpiece. When the magnetic pole rotates and moves with the workpiece relatively, the frictional force generated from MAF cause the abrasives to finish the particles of uneven or free-form surfaces until it becomes smooth. Moreover, the magnetic brush continues to move on the x-y-z direction of the CNC machine, brushing the workpiece until it meets the customer's requirements. 3 2. 2 Dispersion of magnetic force Figure 2-2 shows the free-form magnetic field distribution in the working zone and magnetic force (F) acting on a ferromagnetic particle. In the freeform MAF process, a sufficient quantity of magnetic abrasives is filled in the working zone. Moreover, the inner magnetic field strength is larger than the outer. Therefore, a non-uniformly concentrated magnetic field distribution is formed between the magnetic pole and the workpiece holder. The magnetic force (F) is applied to the magnetic abrasives at position " i " situated at the

outside of the working zone to concentrate and pack them toward the https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishingmaf/

working zone. The magnetic force (F) that acts on the single volume of the magnetic abrasives can be expressed by this formula Equation 2-1 [9]: F =V0 B  $\hat{a}^{+}B / \mu$  (2-1) Where B and  $\hat{a}^{+}B$  are magnetic induction and its gradient in " i " point of the single volume in the working zone and  $\hat{I}_{4}$  is magnetic permeability. Since magnetic permeability of magnetic abrasive is larger than permeability of vacuum  $(\hat{l}_{4} >> \hat{l}_{4})$ . The magnetic force in Equation 2-1 can be expressed as a two dimensional magnetic field distribution following Equation 2-2 [10]  $i\frac{1}{4}$ š Fx = V0 X m  $\mu$  0 H  $\hat{a}$ , H  $\hat{a}$ , x Fy = V0 X m  $\mu$  0 H  $\hat{a}$ , H  $\hat{a}$ , y (2-2) Where Fx is the x component of the magnetic force, Fy is the y component of the magnetic force, x is the direction of the line of magnetic force, y is the direction of the magnetic equipotential line, V0 is the volume of the magnetic particle,  $\hat{I}$ sm is magnetic susceptibility of the particle,  $\hat{l}$ <sup>1</sup>/<sub>4</sub>0 is permeability of vacuum, H is the magnetic field strength at point " i ", and  $i\frac{1}{4}\hat{a}$ , H/ $\hat{a}$ , x $i\frac{1}{4}$ ‰and $i\frac{1}{4}\hat{a}$ ,  $H/\hat{a}^{,}$ ,  $y\ddot{i}^{,}_{4}$ ‰are gradients of magnetic field strength in the x and y directions, respectively. From Equation 2-2, the magnetic force Fx and Fy are proportional to the magnetic particle volume, susceptibility of the magnetic particle, the magnetic field strength and its gradients. The magnetic forces Fx and Fy are also capable of preventing the splashing of the magnetic abrasives caused by the high-speed rotation of the magnetic pole. During finishing process, the congregated magnetic abrasives form a magnetic brush along the line of magnetic force within the working zone, which cause pressure P on the free-form surface and this pressure will act on the work surface. Equation 2-3 represents pressure, P, as follows [10]: if @ if « 1 if ¶if<sup>1</sup>  $if \cdot if^{\circ} / 2p = if^{-} \mu 0 H 2 if - 1 a^{\prime} if - \mu m if \cdot if^{\circ} if if^{\circ} i^{\prime} - 2 - 3i^{\prime} + 3$  $\hat{I}_{4}$ m is the relative magnetic permeability of the magnetic abrasive particle.

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4 The particles on the workpiece surface can be finished out when the magnetic pole absorbs the magnetic abrasives to rotate and move with the workpiece relatively. Therefore, an effective finishing surface can be achieved. From Equation 2-3, P represents the magnetic pressure acting on the workpiece surface and when the magnetic pressure increases so does the material removal rate. This also creates a big finishing depth and affects the surface quality directly. Simultaneously, the resistance force was generated due to the abrasives finishing and the centrifugal force was from a rotating magnetic pole, and their resultant force will enforce the abrasives to splash out of the working zone. However, the splash out phenomenon can be prevented when the high magnetic field is applied and the finishing can be processed smoothly. 3. Experimental mechanism, designs and results 3. 1 MAF mechanism This investigation involved the MAF mechanism illustrated in Figure 3-1. Using a permanent magnet generated the magnetic force; the magnetic field formed a closed loop due to the interaction of the permanent magnet, magnetic abrasives, workpiece, and workpiece holder (S10C steel). The magnetic flux density was close to 1. 2 Tesla in a 1. 0 mm working gap (distance between magnetic pole and workpiece holder). The S pole of the magnet was established with a shank installed in the spindle of the CNC machine. Meanwhile, the N pole of the magnet was designed to absorb the magnetic abrasives. The magnetic pole had an external diameter of 20 mm and a length of 40 mm. Furthermore, the N pole with a 10 mm radius ball shape was processed into four grooves with sizes of 1.5 mm width and 10mm depth to reduce the ball area of the magnetic pole and boost the magnetic field strength for achieving an efficient finishing. 3. 2 Magnetic abrasives The magnetic abrasives must be able to be magnetized (Fe) and https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishing-

maf/

have the ability of finishing (Al2O3). Generally, it is a complex material including the easily magnetized materials includes iron, cobalt, nickel, etc. The materials most commonly used to finish the workpiece in MAF include: aluminum oxide, silicon carbide, boron nitrogen, boron carbide, diamond powder, etc. In this study, the magnetic abrasives were typically mixed with 60wt. % iron powder and 40wt. % aluminum oxide  $(5\hat{l}_{4}m)$ . The abrasives were then compressed into a cylindrical mode and sintered in a vacuum furnace at 1200<sup>°</sup>a, f. Following the sintered process, the magnetic abrasives were crushed into small particles with diameters of approximately  $150\hat{l}_{4}$ m, and the magnetic abrasives became well mixed. During finishing, iron powder and aluminum oxide were difficult to separate since they were cohered after sintering. Figure 3-2 shows the magnetic abrasives under a scanning electronic microscope (SEM, JSM-6360LV type). 3. 3 Experimental designs Objectives of the experimental design, was first to determine which parameters are most influential on the part surface. Then, to determine where to set the influential 5 parameters so that part surface is almost always near the desired target value. In this study, four possible parameters which are spindle speed (S), vibration frequency (F), discharge current(C), abrasive weight ratio (A) considered and used to conduct experiments. In the experiment, four factors with each three levels were selected respectively as Table 3-1 3. 4 Experimental results After the experiments, the collected data (Table 3-2) were analyzed statistically and the ANOVA (Table 3-3) showed the results. After the analyzing, the significant parameters would be applied to develop a surface finish prediction system for the MAF operations using the collected data. 4. The Proposed S-FN-IPSFP System Figure 4-1 illustrates the proposed statistical-assisted fuzzy-nets in-process surface finish https://assignbuster.com/prediction-system-of-magnetic-abrasive-finishingmaf/

prediction (S-FN-IPSFP) system. The inputs of the system were spindle speed (S); vibration frequency (F); discharge current (C); and abrasive weight ratio (A). The predicted variable of the system was the predicted surface finish (Rmax). In order to generate a system with fuzzy-nets theory, a five layers' fuzzy-nets diagram was shown in Figure 4-2, and a five-step approach of constructing the rule bank was introduced as follows. Step 1: Divide the input space into fuzzy regions. The input vectors are: spindle speed (S); vibration frequency (F); discharge current (C); and abrasive weight ratio (A). The ranges for each input variable were: spindle speed (S) [S+, S-] rpm, vibration frequency (F) [F+, F-] times/sec, discharge current (C) [C+, C-] amp, and abrasive weight ratio (A) [A+, A-], where S+and S- were the maximum and minimum values of the spindle speed (S) in all experimental data, respectively. The range of the output variable surface finish (Rmax), was [Rmax +, Rmax ], where Rmax + and Rmax - were the maximum and minimum values of Ra in all experimental data, respectively. Thus, the input feature vector X and " domain intervals" were given as: X = [S, F, C, A]T, â^€ Sâ^^ [S+, S-]; Fâ^^[F+, F-]; â^€ Câ^^ [C+, C-]; â^€ Aâ^^ [A+, A-]; (3-1) The domain interval indicated which variable would most likely lie within the interval based on experience. Each interval was divided into 2K+1 regions, which were denoted by SK, S(K-1), .... MD, .... L(K-1), and LK. 6 The shape of each membership function was triangular and the spread width (W) of each triangular function was the same. For example, the spread width of an input feature S, F, C, and A, is defined as: W (S) =  $+ \hat{a}^{\prime}$  S  $\hat{a}^{\prime}$  S; 2K W(F) = C +  $\hat{a}^{\prime}$ C-;  $A + \hat{a}^{\prime} AF + \hat{a}^{\prime} F$ -; W(C) = W(A) = 2K 2K 2K (3-2) For example, in the feed rate, the membership function with five regions (2K+1=5), therefore, K= 2) had the maximum value of vibration frequency (F + = 10.5 time/sec),

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and the minimum value of vibration frequency (F = 2.375 time/sec). Then, the width of each spread W(F) was equal to (10.5-2.375)/2\*K = 8.125/2\*2= 2.03 time/sec. Therefore, the domain interval was defined as [2.325] time/sec, 10. 5 time/sec]. Figure 4-3 depicts the domain interval of F divided into five regions. Step 2: Generate fuzzy rules for the given data pairs. The fuzzy-nets training procedure was based on the input and output signals collected from the experiment. The signal obtained from the control system generated the input feature vector X (Eq. 3-1). The output surface finish (Rmax) indicated the output vector of the system. The input-output data pairs are: (S(t), F(t), C(t), A (t), R max (t),  $\hat{I}_{4}^{1}$  R max) (t) where t denotes the number of the training data set, Rmax denotes the output class, and  $\hat{I}_{4}^{\prime}$ Ra denotes a degree of this data set, which was assigned by a human expert. The following example of fuzzy degree of the input variable (Fi) was determined in different regions. The function is given as:  $i \exists f \pm (Fi a^{2} c(F))$  $1\hat{a}^{\prime}$ ,  $i\hat{f}^{\prime}$  W(Fi )  $i\hat{f}^{\prime}$  if (c(F i )  $\hat{a}^{\prime}$  Fi ),  $\hat{l}_{4}^{\prime}$  F (F(i) ) =  $i\hat{f}^{2}1\hat{a}^{\prime}$  W(Fi )  $i\hat{f}^{\prime}$  if  $i\hat{f}^{\prime}$  if  $if_{3} 0, i[]if_{4} F \hat{a}^{1} c(Fi), c(Fi) + W(F)if_{1} iif_{1} if_{1} if_{1} \hat{a}^{1} c(Fi) \hat{a}^{1} W(F),$ c(Fi )  $if_{2}$   $if_{1}$   $if_{1}$   $if_{1}$  otherwise  $if_{3}$  [] (3-3) where c(Fi) and W(Fi) indicate the center point and the spread width of the input linguistic variable Fi (e.g. S2, S1, MD, L1 or L2); and i is the index of regions, in which i = 2K+1. For example, the input-output training data set 41th is given as Table 3-2: [S(41), F(41), C(41), A(41), Rmax (41)] = [1000 rpm, 5 times/sec, 2 amp, 0.5, and 0. 34 µin]. 7 The fuzzy rule regions and the degrees of these input and output values are depicted in Figures 4-4 and 4-5. The membership values of each data set (S(41), F(41), C(41), A(41), and Rmax (41)) are:  $[\mu MD(S(41)) =$ 0. 91 and  $\mu$ S1(S(41))= 0. 09]; [ $\mu$ S1(F(41))= 0. 94 and  $\mu$ S2(F(41))= 0. 06];  $[\mu MD(C(41)) = 0.92 \text{ and } \mu S1(C(41)) = 0.08]; [\mu MD(A(41)) = 0.97 \text{ and } \mu S1(C(41)) = 0.97 \text{ and } \mu S1(C(41)) = 0.97 \text{ and } \mu S1(C(41)) = 0.08];$ 

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 $\mu$ S1(A(41))= 0. 03]; and [ $\mu$ S1(Rmax (41))= 0. 89 and  $\mu$ MD(Rmax (41))= 0. 11]. Therefore, the maximum fuzzy values of each membership value for (S(41), F(41), C(41), and Rmax (41)) are  $[\mu MD(S(41)) = 0.91, \mu S2(F(41)) = 0.$ 94,  $\mu$ MD(C(41))= 0. 92,  $\mu$ MD(A(41))= 0. 97, and  $\mu$ MD(Rmax (41))= 0. 89]. Then, one fuzzy rule was generated as: A(41), IF { S(41) is MD  $^{1}$  F(41) is S1  $^{C}(41)$  is MD  $^{A}(41)$  is MD}, THEN { Rmax (41) is S1}. where  $^{I}$  indicated that all the conditions of the IF statement must be met simultaneously for the THEN statement to be true. Step 3: Avoid conflicting rules. It was possible to have two or more conflicting rules from the experiments, i.e., rules that have the same IF part but a different THEN part. Top-down and bottom-up methodologies were proposed to resolve this conflict (Lou [11]). The top-down methodology assigned a degree to each rule. The degree of rule i {IF S is MD, F is L1, C is L1, and A is L1, THEN Rmax is MD} is defined as: d (Rulei) =  $\mu$  (S)  $\mu$  (F)  $\mu$  MD L1 L1 (C)  $\mu$  L1 (A)  $\mu$  MD (Rmax)  $\mu$  (3-4) E where  $\mu E$  is the data pair degree assigned by a human expert based on the data collection condition. Note that MD and L1 are linguistic values for the input vectors and the output. An example of two conflicting rules is: Rule i: IF{S is MD, ^ F is MD, ^ C is MD, ^ A is L1} THEN { Rmax is MD}; Rule j: IF{ Sis MD, ^ F is MD, ^ C is MD, ^ A is L1} THEN { Rmax is L1}; The degree of each rule is: d (Rulei) =  $\mu$  MD (S)  $\mu$  MD (F)  $\mu$  MD (C)  $\mu$  (A)  $\mu$  L1 MD (R max )  $\mu$  8 (3-5) E d ( Rule j) =  $\mu$  MD (S)  $\mu$  MD (F)  $\mu$  MD (C)  $\mu$  (A)  $\mu$  (R max )  $\mu$  L1 L1 (3-6) E The following strategy was used to resolve conflicting rules. If the magnitude of the deviation  $| d(Rule i) - d(Rule j) | > \hat{l}'$ , where  $0 < \hat{l}'$