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FORMATION AND CONTROL OF A ROTATING MAGNETIC FIELD IN MAGNETIC ABRASIVE FINISHING

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Introduction

Surface finishing is the final operation in manufacturing processes and it costs around 15% of the total manufacturing cost [1]. A high quality surface with very low values of surface roughness and high accuracy are required for some products in many applications. These characteristics are required especially for products with a complex shape which are made from advanced materials such as alloys of hard materials, glass, and ceramics.

Magnetic field, on the other hand, has assisted a wide spectrum of manufacturing techniques in finishing, cleaning, deburring, and burnishing for difficult to machine materials. Magnetic field has been employed in a number of manufacturing processes to control the effective parameters of these processes. Moreover, it's used to overcome the limitations of traditional finishing processes in terms of accuracy and cost, due to the high strength rigid tools. Magnetic Abrasive Flow Machining (MAFM), Magnetic Float Polishing (MFP), Magnetorheological Abrasive Flow Finishing (MRAFF), and Magnetic Abrasive Finishing (MAF) are some examples for these manufacturing processes. [2-4].

Magnetic Abrasive Finishing (MAF) technique is one of the advanced and nonconventional finishing processes, in which magnetic field is used to produce a high quality finished surface efficiently and economically [2]. In MAF technique, a workpiece is placed in a magnetic field which is produced by a permanent magnet or an electromagnet. The working gap between the workpiece and the magnetic source fills with the Magnetic Abrasive Particles (MAPs). Applying a relative motion between the magnetic source and the workpiece makes MAPs scratch the surface of the workpiece and remove a thin layer with a Micro or Nano scale in a form of fine chips. In Magnetic Abrasive Finishing (MAF) cutting force is controlled by the magnetic field. Thus, the formation of microcracks, which are mainly caused by the normal stresses, will be minimized due to the controlled forces applied on the abrasive particles.

Process Principles and Experimental Set-up

The new set-up uses a rotating magnetic field to control the finishing process for a flat plate. The first attempt of using a rotating magnetic field in MAF process has been conducted by Shinmura et al. They applied a rotating magnetic field to finish external [5] and internal [6] surfaces of a cylindrical workpieces. The workpieces were installed on the table of a vertical milling machine. A rotating magnetic field was produced by electrifying three-coils arranged in the direction of 120° interval with a three phase AC current. Most of the previous work in the literature uses a mechanical power to produce a rotating motion for the workpiece or the magnetic source. That motivated us to propose a new stationary setup. The general principle of the new setup is shown in Fig. 1. The proposed setup is a stationary system that depends on a rotating magnetic field to move MAPs on the workpiece surface. This magnetic field is produced by electrifying the electromagnets in a specific pattern. This system does not need machine equipment or any type of motor. The magnetic force F_m acting on MAPs in the working area has a magnitude of:

$$F_m=\mu_o v(M\cdot\nabla)H \qquad (1)$$

where μ_o represents the magnetic permeability in vacuum, v represents the volume of the magnetic abrasive particle, M represents the magnetization of the magnetic abrasive particle in the working area, H represents the magnetic flux intensity, and ∇ is the gradient notation.

The proposed system in this study contains a software and many hardware components. The software component represents a MATLAB-Simulink file. Its primary purpose is to simulate the system based on a mathematical model that governing the main parameters depending on this application. The hardware components contain a dSPACE machine which serves as a data acquisition device. The data source comes from the Simulink file. Secondly, an amplifier and power supply which supplies the dSPACE device and L298 Dual Full-Bridge Drives.

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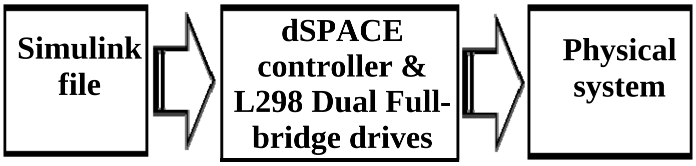

Fig. 1 The proposed system concept.

The L298 Dual Full-Bridge Drives control the direction of the current which then controls the polarity of the electromagnet (coils): either North (N) or South (S) Pole. The third part of the hardware components is the physical system which contains four-cylindrical electromagnets. Each electromagnet contains a coil with 1000 turns of a copper wire (AWG 22) around an iron core. The diameter of the coil is 40mm and the height is also 40mm. The iron core diameter is 20mm and the height is 50mm. The electromagnetic coils are inclined with respect to the vertical axis with an angle of 30°.

Control

To be able to perform experiments and test the proposed concept, a control module which controls the electromagnets is essential. Fig. 2 shows a flow chart of the communication from the MATLAB file to the physical system. In this application, the electromagnets are controlled through a dSPACE device.

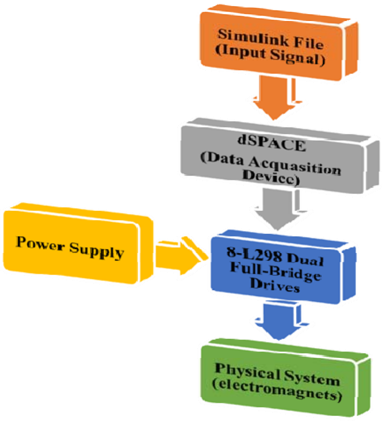

Fig. 2 Flow chart of the system communication.

The use of L298 Dual Full-Bridge Drives is to solve the problem of residual magnetism for the iron core of the electromagnet. This phenomenon happens to ferromagnetic material when it is constantly being charged in a single direction of current, obtaining a single pole facing the particles. The function of L298 Dual Full-Bridge Drives is to manipulate the direction of the current passing through the coil and control its polarity with North (N) or South (S) Pole.

MATLAB Simulink

Simulink is needed to program the desired signal and thus control the electromagnets' excitation, for example, the timing for on and off signals of the electromagnets. The challenge involves designing a signal such that the pattern of the magnetic field generated at each coil can produce a Flexible Magnetic Abrasive Brush (FMAB) in the working gap with the presence of MAPs as shown in Fig. 3, and move MAPs from point A to point B horizontally (not vertically) on the workpiece surface to perform the finishing process.

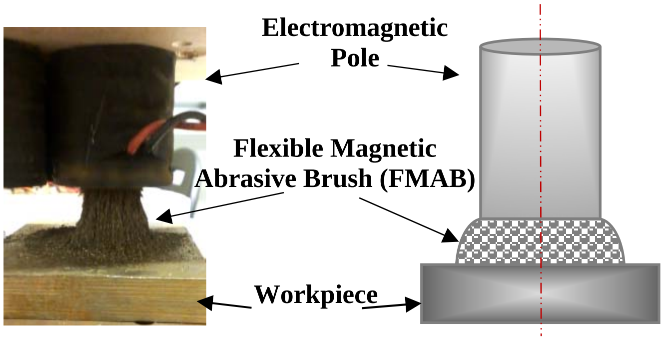

Fig. 3 Flexible Magnetic Abrasive Brush (FMAB).

The output signal from Simulink + dSPACE is an analog, while the L298 Dual Full-Bridge Drives work with a digital signal. Therefore, Pulse Width Modulation (PWM) technique is used to convert the analog signal into a digital signal.

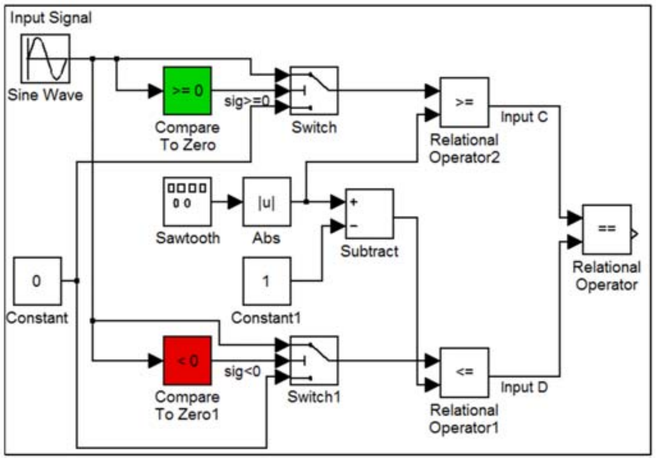

Fig. 4 Simulink Block Diagram for PWM.

The algorithm of conversion from analog signal to digital signal through PWM is incorporated into the overall Simulink file for the four-coil configuration shown in Fig. 5. It is reduced into a simple block circled by an orange rectangle.

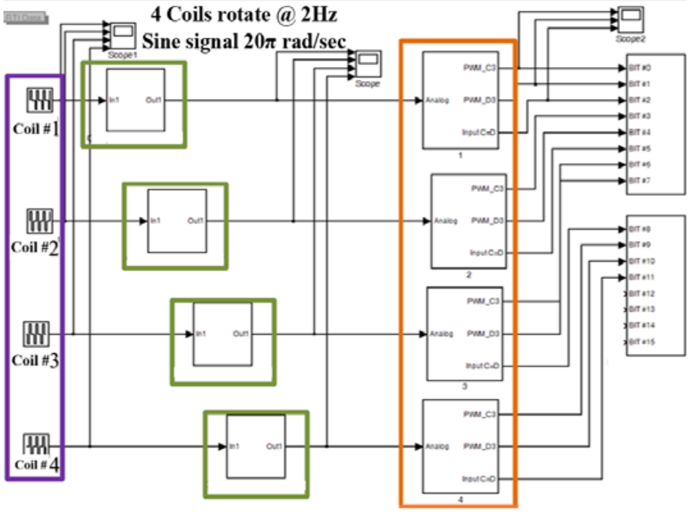

Fig. 5 MATLAB simulink model.

On the left side of Fig. 5 above, the four blocks circled by a purple rectangle are the general pattern of the signal for each coil. In other words, this pattern dictates when the current passes through the coil and when it does not. With four-coil configuration, MAPs need to move from one point to another point in a circular path in order to perform the finishing process. The ideal pattern ensures that MAPs move in a circular or semicircular path on the workpiece surface, and there is no residual magnetism within each coil. To make MAPs move, only two neighboring coils will be activated. For example, Coil 1 and 2, at time 1, will have North Pole and the others will be neutral (not activated). At time 2, the next pair of coils, Coil 2 and 3, will have South Pole. Therefore, Coil 2 will change from North Pole to South Pole. The general pattern is summarized in Table I. The coils' actuated signals are programmed and represented by the blocks encircled by the purple rectangle. It is important to note that there is attraction force to the magnetic particles regardless of which pole the coil has. The alternation of poles is to minimize residual magnetism at the core. To further avoid magnetization of the electromagnets, the general pattern signal, illustrated in Fig. 6, entered a function block that converts a +1 signal or a -1 signal into a high frequency sinusoidal wave that changes from +1 and -1.

Table I. The general pattern of coils activation.

#/Time Coil	1	2	3	4	5	6	7	8
Coil 1	+1	0	0	-1	+1	0	0	-1
Coil 2	+1	-1	0	0	+1	-1	0	0
Coil 3	0	-1	+1	0	0	-1	+1	0
Coil 4	0	0	+1	-1	0	0	+1	-1

Note: Signal for North Pole=+1, Neutral (no current supply) =0, and South Pole=-1

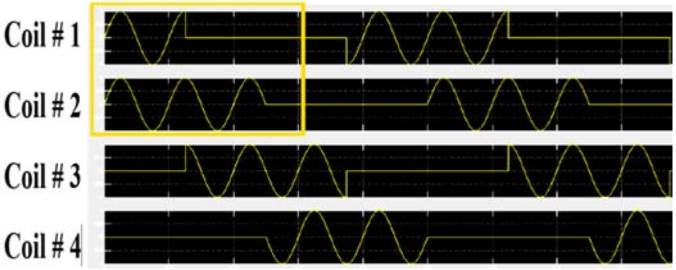

Fig. 6 General pattern for 4-electromagnets configuration.

Conclusion

The developed setup for abrasive finishing uses rotational magnetic fields, which does not require any mechanical moving parts to perform the finishing process. The pattern of coils' excitation was tested with 2 Hz frequency 28 volts and a rotating magnetic field was obtained. It was observed that the particles can move on the workpiece surface according to the movement of the magnetic field. The reliability of this setup will be validated by applying this technique to finish surfaces of different materials.

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