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Optimization of Parameters for Uniform Magnetic Field

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***Abstract*— Research involving the interaction of magnetic field with various engineering process have started gaining attention in recent years. Magnetic field has been used to improve various manufacturing processes or alter the physical conditions to generate a favorable output. Prominent applications of magnetic field are in the areas of mixing of fluids, fabrication of nanoparticles and weld confinement. A major challenge so far has been to generate a magnetic field and identify regions of uniform flux. This paper presents a systematic study of various parameters affecting the magnetic field like magnetization orientation and number of magnets. Furthermore, different physical arrangements of magnets are evaluated using finite element simulation to generate magnetic field. Regions of uniform magnetic field are identified using these simulation results. These results can be used for further applications requiring uniform magnetic fields.**

Keywords—Finite element simulation; magnetic field; magnets orientation; uniform flux.

I. Introduction

Manufacturing processes have come long way from stone age methods of chipping away stones to the modern complex additive techniques. Development and application of LASERs in manufacturing processes has opened vistas of opportunities in machining of various materials. Lasers are now extensively used to machine materials which are hard to machine by using conventional techniques. The earliest lasers had pulse duration in the range of a few microseconds but later on ultrashort lasers were developed with pulse duration in the range of femtoseconds. Material removal using microsecond lasers is a thermal process involving phase change of materials with the laser acting as a source of heat whereas ultrashort pulses involves electronic interactions and generation of plasma. This makes laser induced plasma machining a very complex process to understand and control. Plasma is basically a dense cloud of charged particles of free electrons and ions. Confinement of plasma and maintaining optimum plasma parameters like plasma temperature and electron density is a challenging task. Researchers have tried to use external magnetic field to manipulate plasma in laser machining [1, 2]. Using various configurations of Neodymium magnets the authors were able to machine micro features with high aspect ratios by uniaxially squeezing the plasma using external magnetic field. Maintaining optimum plasma density in CO_2 laser welding is important because high plasma density leads to shielding effect and defocusing of the laser beam and thus reduces the efficiency of the process. H. C. Tse et al have used magnetic field to control the plasma behaviour to improve the penetration depth of the laser beam in drilling operation [3]. M. Khaleeq-ur-Rehaman et al studied the effect of an external magnetic field on the parameters of electrons from laser induced plasma. The presence of transverse external magnetic fields significantly reduced the electron current, temperature and energy of electrons. Their experiments also showed confinement of plasma and higher electron temperature after a certain depth in the presence of magnetic field [4].

Another major application of magnetic field has been in confinement and manipulation of weld pool dynamics. Development of Fibre lasers with output powers of nearly 50 kW has made it a suitable candidate for wide industrial applications. Lasers are widely used in welding of Aluminium alloys in aerospace industry. Aluminium has high heat conductivity in its liquid state which cause formation wide weld beads and a characteristic wineglass shape of weld crossection. M. Bachmann et al investigated the effects of external magnetic field on weld pool dynamics in high power laser welding of aluminium. The external magnetic field has a decelerating effect on the flow velocities in weld pool resulting in shortened weld bead. They also observed complete elimination of the wineglass shape of weld bead. Despite the advancements in laser welding, machining high aspect ratio features and deep penetrating laser drilling operations face challenges like porosity formation. Similarly magnetic field has been used to reduce weld pores and weld surface roughness in welding of aluminium alloys [5]. Zhou et al successfully used electromagnetic forces to increase the backfilling velocity of molten weld pool in keyhole drilling to reduce porosity [6]. M. Gatzen et al used a low frequency magnetic field to improve the silicon distribution in aluminium welding using filler material. Increased dilution of silicon from the filler wire was observed at magnetic flux densities higher than 200 mT [7].

In all the above mentioned applications the magnetic field has to be uniform and should have sufficient field strength to bring out noticeable changes in the manufacturing process. In this paper the effect of various parameters on magnetic field is

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studied through simulation. The authors have tried to achieve uniform magnetic field using permanent magnets.

II. Simulation Procedure

A finite element model has been used in this simulation. Figure 1 shows the arrangement of magnets used in which has been used for validation in this paper. In this model four Neodymium magnets are used which has a dimension of 20 mm x 13.4 mm. The specifications of the magnetic properties are given in Table 1.

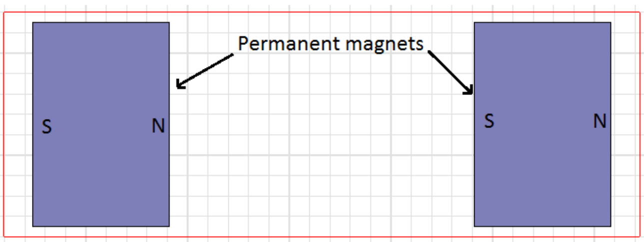

Fig. 1. Arrangement of magnets in a four magnet configuration

TABLE 1. Magnetic Properties Of Neodymium Magnets

	Properties		
	Properties	*Value*	*Units*
1.	Maximum Energy Product	16.94	MGOe
2.	Residual Induction	8.67	kG
3.	Coercive force	6.97	kOe

The same model will be used throughout this simulation to study the effects of various parameters on the magnetic field. The various parameters that will be studied are

- Distance between magnets
- Number of magnets
- Arrangement of magnets

III. Results and Discussions

Figure 2. (a) shows the most basic arrangement using two permanent magnets. The magnets are separated by distance of 20 mm with the opposite poles facing each other and it can be seen that the uniform magnetic field at the center is 0.24 T. The magnetic field lines flow from the north pole to south pole outside the magnet as shown in figure 2b. A major drawback with this arrangement is that the region of uniform magnetic field is very less at the center measuring less than 5 mm longitudinally. Also, the space between the two magnets is only 20 mm; this places limitations on the dimension of the work piece and difficulties in handling the job.

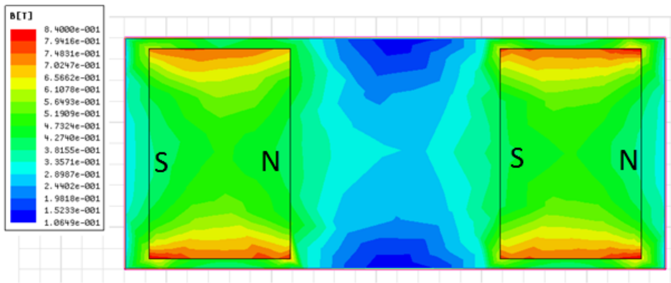

Fig. 2. (a). Magnetic field contour plot using 2 permanent Neodymium magnets separated by 20mm.

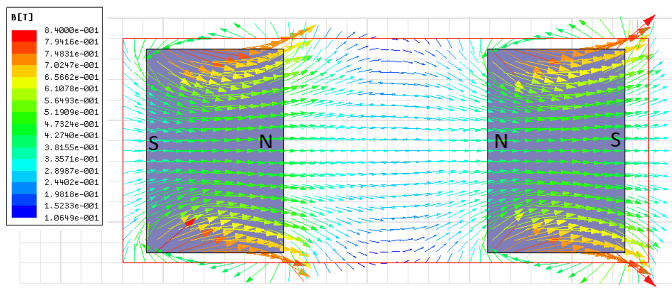

Fig. 2. (b). Magnetic field vector plot for the arrangement

In figure 3, the magnetic field generated by two same poles facing each other is shown. The magnetic field lines repel each other and a circular region of uniform magnetic field is formed. This field is however very weak compared to the previous arrangement.

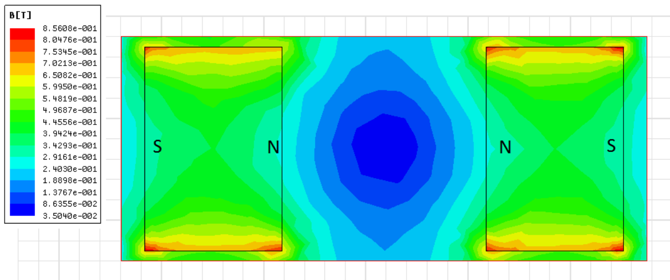

Fig. 3. Magnetic field contour plot using 2 permanent Neodymium magnets separated by 20mm with same poles facing each other.

In order to overcome the space limitations in the above arrangement it is necessary to increase the distance between the magnets. Figures 4. (a) and 4.(b) shows the resultant magnetic fields of two magnets separated by 25 mm and 30 mm. The region of uniform magnetic field is again very small in 4(a) compared to 4.(b) but the former has higher field strength. Here a compromise has to be made between work dimensions and magnetic field strength while choosing the distance between magnets. As the distance between magnets increases the strength of the magnetic field decreases but the area of uniform magnetic field region increases.

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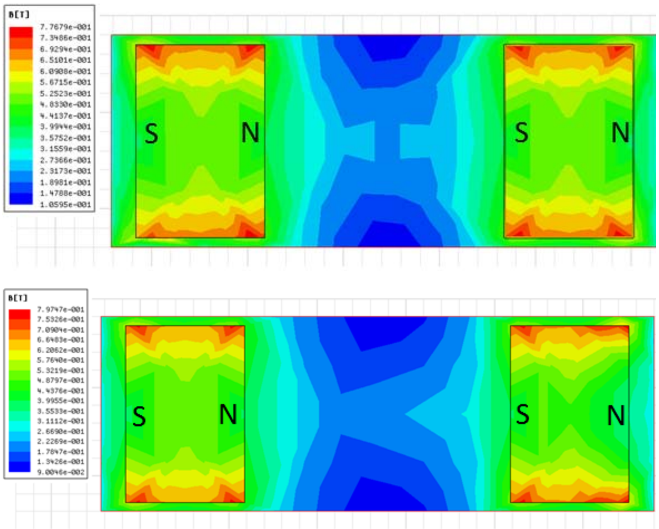

Fig .4. Magnetic field vector plot using 3 permanent Neodymium magnets separated by (a) 25 mm and (b) 30 mm.

Figure 5 shows an arrangement involving three magnets equally inclined to each other by 60^0. The magnets are arranged in a triangular manner with two north poles and one south pole facing each other as shown. The weakest magnetic field region is formed nearer to the north poles and has strength of 0.0208 T. At the center of the arrangement, the field strength is nearly 0.36 T. The direction of magnetic field lines is shown in figure 6.

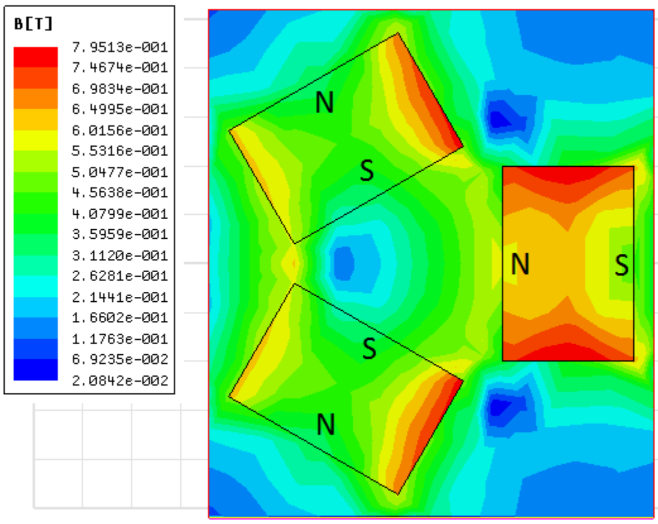

Fig. 5. Magnetic field contour plot using 3 permanent Neodymium magnets

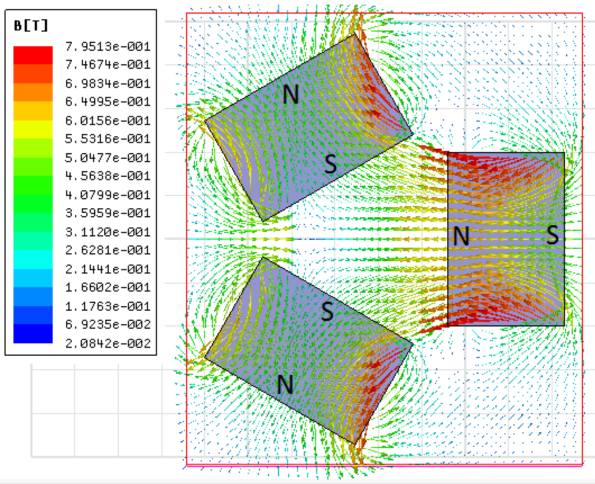

Fig. 6. Magnetic field vector plot using 3 permanent Neodymium magnets

The use of a three magnet arrangement is however not recommended because of the difficulty in arranging the magnets. The magnets have to be placed exactly at 60^0 inclinations to each other in a symmetric fashion. Any slight deviation may cause a huge distortion in the generated magnetic field and it may prove to be difficult to identify regions of uniform magnetic field.

Figure 7 shows a four magnet arrangement which is symmetric and the distance between each magnet is 28 mm. The poles are arranged in alternate order as shown in the figure and this arrangement can be called a straight arrangement. The region of weakest magnetic field is at the center having strength of 1.776×10^{-04} T. An important observation is that the regions of uniform magnetic field are shaped as annular rings from the center. The strength of each ring progressively increases as the distance from the center increases.

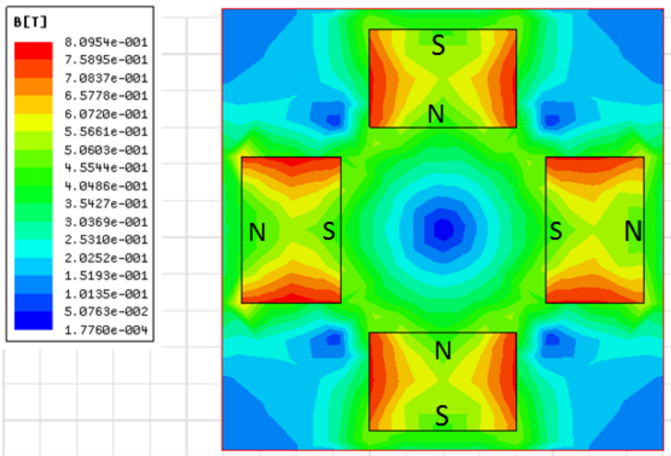

Fig. 7. Magnetic field contour plot using 4 permanent Neodymium magnets in straight arrangement

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The direction of magnetic field lines for the straight arrangement is shown in figure 8. The lines flow from the North Pole to the nearest south poles. This flow of field lines gives them a confining action at the center. The straight arrangement can be therefore used for confinement of magnetic materials like molten metal and plasma cloud.

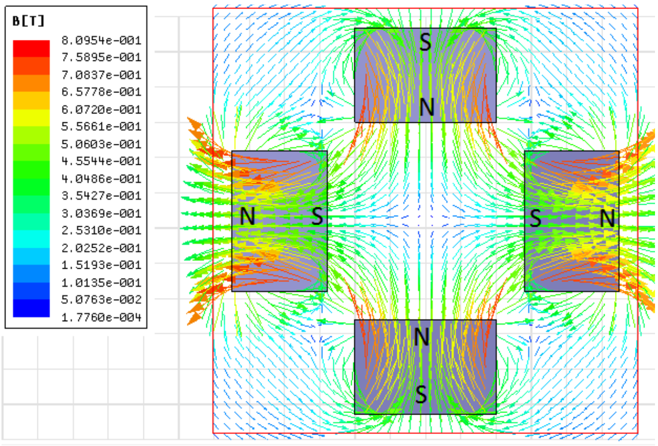

Fig.8. Magnetic field vector plot using 4 permanent Neodymium magnets in straight arrangement

Figure 9 shows four magnets arranged with opposite poles facing each other. This configuration can be called reverse arrangement. In this arrangement there are two regions of uniform field where the weakest strength of 0.01 T is observed. At the center of the arrangement the magnetic field has strength of 0.27 T which is higher than all previous cases.

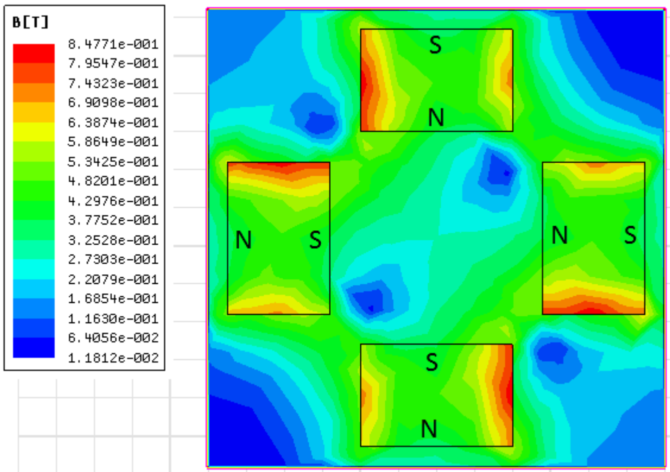

Fig. 9. Magnetic field contour plot using 4 permanent Neodymium magnets in reverse arrangement

The direction of magnetic field lines for reverse arrangement is shown in figure 10. The field lines flow from the north poles to the adjacent south poles. It is observed that the field has a uniform direction flowing diagonally. This field orientation can be used for uniaxial squeezing the plasma along a particular direction.

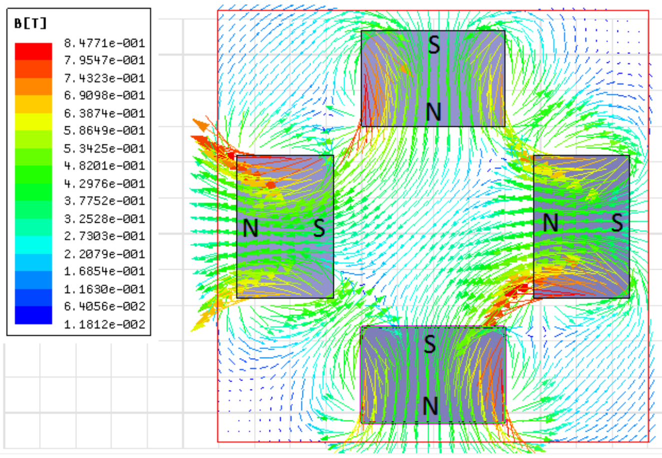

Fig.10. Magnetic field vector plot using 4 permanent Neodymium magnets in reverse arrangement

IV. Conclusion

The finite element simulation of magnetic field using commercially available software for different arrangements of magnets were studied by varying parameters like number of magnets and arrangement of magnets. The first arrangement used two magnets and results showed that the magnetic field strength reduces as the distance between the magnets increases but the area of uniform field region increases. The three-magnet arrangement generated high field strength but it is not recommended because of difficulties in arranging the magnets. The results show that strongest magnetic field region at the center was observed in a four-magnet reverse arrangement. By varying the configuration of poles the direction of magnetic field can be altered to create a confining or squeezing action. The straight arrangement can be used for plasma confinement and reverse arrangement for uniaxial squeezing of plasma.

References

[1] S. Wolff and I. Saxena, "A preliminary study on the effect of external magnetic fields on Laser-induced plasma machining (LIPMM)," Manufacturing Letters 2, 54-59, 2014.

[2] R. Malhotra, I. Saxena and K. Ehmann, "Laser-induced plasma micro-machining (LIPMM) for enhanced productivity and flexibility in laser-based micro-machining, " CIRP- Annals Manufacturing Technology, 211-214, 2013.

[3] H.C. Tse, H.C. Man and T.M. Yue, "Effect of electric and magnetic fields on plasma control during CO_2 laser welding," Optics and Lasers in Engineering 32, 55-63, 1999.

[4] MM. Khaleeq-ur-Rahman, K.A. Bhatti, M.S. Rafique, A. Latif and K.T. Chaudhary, " Magnetic field effect on electron emission from plasma," Vacuum 83, 936–941, 2009.

ISBN: 978−81−925974−3−0

[5] A. Schneider, V. Avilov, A. Gumenyuk and M. Rethmeier, "Laser beam welding of aluminum alloys under the influence of an electromagnetic field," Lasers in Manufacturing Conference 2013, Physics Procedia 41, 4 – 11, 2013.

[6] Marcel Bachmann, Vjaceslav Avilov, Andrey Gumenyuk and Michael Rethmeier, "About the influence of a steady magnetic field on weld pool dynamics in partial penetration high power laser beam welding of thick aluminium, " International Journal of Heat and Mass Transfer 60, 309–321, 2013.

[7] M. Gatzen, "Influence of low-frequency magnetic fields during laser beam welding of Al with filler wire, " LANE-2012- Physics Proceedia 39, 59-66, 2012.

[8] Manas Das,V. K. Jain and P. S. Ghoshdastidar, "Nanofinishing of flat workpieces using rotational–magnetorheological abrasive flow finishing (R-MRAFF) process," International Journal of Advanced Manufacturing Technology 62, 405-420, 2012.

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