Three-Dimensional Numerical Study of the Magnetic Effect on the Air Flow at an Intake

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Magnets attract the air which is paramagnetic and give influences to air flows. In this study, air flows at an intake with magnetic fields are examined by means of three-dimensional numerical simulation. The flow is assumed to be compressible and inviscid. Under the magnetic fields, vortices are generated near the magnet by magnetic forces. Vortices disturb the air flow and relieve the flow congestion. The flow rate at the intake with magnets increases rapidly and it becomes almost three times as large as that without the magnetic fields.

1 Introduction

Various magnetooerodynamic phenomena caused by the character of the air which is attracted by magnets have been experimentally found by Wakayama, one of the authors and coworkers. These include, for example, the generation of air flows, the promotion of combustion, the support of breathing, and so forth. Regarding the promotion of combustion, its application under microgravity has also been reported.

In this study, breathing support using magnets is considered to be a final goal. The speedup of the air flow in breathing has been observed experimentally, when a test subject had tubes inserted into his nostrils; each tube had a pair of magnets at the opposite end. This result suggests the possibility of the application of magnets to breathing support for athletes or individuals with respiratory disorders.

It remained unknown, however, how a pair of magnets which creates a symmetrical magnetic field could attract the air and exerted one way acceleration on the air flow. Thus we intended to clarify the mechanism of this phenomenon, i.e. the interaction between the magnetic field and the air flow by means of the numerical simulation. In the previous paper, we performed a two-dimensional numerical simulation and obtained the result that the flow rate under the magnetic field was almost three times as large as that without the magnetic field. It was observed that the magnetic force stirred the air and relieved the congestion of air flow leading to the increase of the flow rate.

In this paper, we perform a three-dimensional numerical simulation and verify the result of two-dimensional simulation in the magnetic effect on the air flow at an intake. The air flow caused by the pressure difference is studied by means of the three-dimensional numerical simulation and the flow rate at an intake where magnets exist is calculated to determine the effect of the magnetic field.

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2 Magnetic Force

There are two types of magnetic forces. One is the Lorentz force which is exerted on charged particles in motion. The other is the Coulomb magnetic force by which magnets attract ferromagnets or paramagnets, or repel diamagnets. In this study, it is assumed that only the Coulomb magnetic force participates in the system since the air is chemically stable and the velocity of the flow is too low to ionize the air. Hence, in this paper the “magnetic force” means the “Coulomb magnetic force” hereafter.

The magnetic force \( f \) in a CGS system of units (cgs) electromagnetic system of units (emu) exerted to the unit mass of a substance is expressed as follows:

\[
f = \chi (B \cdot \nabla) B = \nabla \left( \frac{1}{2} \chi |B|^2 \right)
\]

(1)

where \( \chi \) is the magnetic susceptibility per unit mass of the substance, and \( B \) is the magnetic flux density. The magnetic susceptibility per unit mass of the air is \( 24.1 \times 10^{-9} \text{ cm}^3\text{g}^{-1} \) (in cgs) \(^8\). The right-hand of eq. (1) is valid for the case where there is no temporal variation of the electric field and no electric current. The magnetic force is proportional to the gradient of the magnetic potential energy multiplied by -1. Equation (1) means that the magnetic force is a body force, a conservative force and a force which appears due to the nonuniformity of the magnetic field.

3 Description of the Calculation

The computational area is shown in Fig. 1.

![Fig. 1: Computational area.](image)

The left space is connected to the right space via a straight channel. The width (y direction) of the channel is 1 cm and its length (x direction) is 3 cm. The bold and thin lines in Fig. 1 indicate walls and far boundaries, respectively. The left space corresponds to the open air and its initial pressure is set to the atmospheric pressure \( p_0 \). The right space corresponds to the space within the human body and its initial pressure is set to \( p_0 - \delta p \) which is slightly lower than \( p_0 \). The pressure difference \( \delta p \) is determined to be \( 2.8 \times 10^{-8} \text{ atm} \), which is derived from Bernoulli's theorem under the conditions of normal breathing. A pair of 1-cm-wide (x direction) and 0.5-cm-long (y direction) magnets is located at the left end of the channel, as shown in Fig. 1. The calculation starts when the shutter at the right end of the channel opens instantaneously. The
computational range in z direction is 0.75 cm and the thickness of the magnets in z direction is 0.7 cm.

We assume that the flows are symmetrical with respect to the center plane (y = 0) indicated by dashed lines in Fig. 1. Thus the three-dimensional calculations are carried out in the upper-half area of the region. The flow rate at the intake of the channel (x = 0.025 cm) is calculated under the magnetic field as well as without the magnetic field.

Magnetic field is obtained by Biot-Savart’s law using equivalent electric circuits with magnetic shells of the magnets which are parallel to xz plane. The thickness (y direction) of each magnetic shell is assumed to be 0.05 cm and each electric circuit is divided into line elements of 0.05-cm-long. Magnetic field at each observation point (lattice point) is computed by summing up each effect (∆B) from all line elements (∆l) as follows:

$$\Delta B = I \Delta l \times \frac{r}{r^3}$$  \hspace{1cm} (2)

where r is a position vector which starts at the line element and ends at the observation point, and r is magnitude of r. Magnitude of electric current (I) is adjusted to fit the magnetic field.

Projections on xy and xz planes of the magnetic force vectors exerted on the air of unit mass obtained by eqs. (1) and (2) are shown in Fig. 2.

Magnitude of the magnetic field is set to 0.4 T at the center of magnets gap indicated by a small disk in Fig. 2.

It is impossible to compute the effect of the conservative force on the fluid when it is assumed to be incompressible, since the governing equations of the flow under the conservative force is formally the same as that without the conservative force. Therefore, in this paper, the air is assumed to be compressible although the fluid velocity is much lower than the sound velocity. We carried out the calculation based on the Euler equation (eq. (3)) together with the equation of state for the ideal gas (eq. (4)).

Fig. 2. : Magnetic force exerted on the air of unit mass. Arrows indicate force vectors. The left diagram is the force field in xy plane near the center of magnet thickness (z = 0.375 cm) and the right diagram is that in xz plane near the center of magnet width (x = 0.475 cm).

$$\frac{\partial U}{\partial t} + \frac{\partial E}{\partial x} + \frac{\partial F}{\partial y} + \frac{\partial G}{\partial z} - H = 0$$  \hspace{1cm} (3)
\[ U = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ e \end{bmatrix}, \quad E = \begin{bmatrix} \rho u \\ \rho u^2 + p \\ \rho u v \\ \rho u w \\ (e + p)u \end{bmatrix}, \quad F = \begin{bmatrix} \rho v \\ \rho u v \\ \rho v^2 + p \\ \rho v w \\ (e + p)v \end{bmatrix}, \quad G = \begin{bmatrix} \rho w \\ \rho u w \\ \rho w^2 + p \\ \rho w v \\ (e + p)w \end{bmatrix}, \quad H = \begin{bmatrix} 0 \\ \rho f_x \\ \rho f_y \\ \rho f_z \end{bmatrix} \]

\[ e = \frac{\gamma}{\gamma - 1} + \frac{1}{2}(\rho u^2 + \rho v^2 + \rho w^2) \]

McCormack's explicit method is used to integrate eq. (3). Artificial viscous terms are added to stabilize the computation. The grid system used in the calculation on \( xy \) plane is orthogonal and non-uniform and that on \( z \) direction is orthogonal and uniform with 0.05 cm interval. The grids on \( xy \) plane are shown in Fig. 3. The finest grid interval is 0.05 cm. Physical values such as the density and velocity are defined at the center of neighboring grid lines in all directions so that values on the wall need not be evaluated.

![Grid lines](image)

Fig. 3. : Grid lines. Computation is carried out for the upper half (\( y \geq 0 \)) area of the region.

### 4 Results and Discussion

Time history of the flow rate at the intake (\( x = 0.025 \) cm) of each case is shown in Fig. 4.

![Flow rate vs. time](image)

Fig. 4. : Time history of flow rate at the intake.

Flow rate \( q \) is defined as \( q = \int \rho u dy dz / (\rho_0 \Delta y \Delta z) \), where \( \Delta y \Delta z \) is a cross sectional area of the channel width, \( \rho_0 \) is the initial air density under the atmospheric pressure \( p_0 \) and the integration is carried out over the cross section of the channel.
In case 2, the increase in the flow rate is larger than that of case 1 from $t = 0$ s to $t = 0.75$ s where the flow rate is almost three-times as large as that of case 1.

Fig. 5.: Projections of flow vectors on $xy$ plane at the intake of both cases in time sequences. (Diagrams are drawn with "post-kun" developed in Fujii Lab.)

In Fig. 5, projections of flow vectors on $xy$ plane at the intake near the center of magnet ($z = 0.375$ cm) for both cases are shown at various time sequentially. Each time in the figure corresponds to the arrow indicated in Fig. 4.

At $t = 0.01$ s, it is observed that vortices start to be generated near the magnet corners in case 2. Consulting with the magnetic force diagram on $xy$ plane in Fig. 2, it is realized that some strong force vectors near magnet corners have caused these vortices. Furthermore, the flow from left-upper space toward the left magnet corner also appear. This flow is caused by the strong force vector at the left magnet corner which is pointing the right-downward direction. These phenomena are not seen in case 1 where no magnet exists.
At $t = 0.12$ s, magnitude of vortices reaches its maximum value in case 2. The fluid from left-upper space overflows the channel and begins to flow towards the left open space.

Vortices in case 2 decrease their strength and are fading out after $t = 0.12$ s, however, strong flows caused by vortices do not disappear and the flow rate into the channel increase effectively. On the other hand, magnitude of flow vectors increases gradually in case 1, although their directions in left space are all pointing the channel intake, which causes the flow congestion.

Mechanism of the increase of the flow rate under the magnetic field is considered as follows; the magnetic force causes vortices at the entrance of a pipe where air flow is congesting, the vortices disturb the air flow and relieve the congestion, then the air flow increases.

The same result is obtained with 3D simulation as with 2D simulation in following points; under the magnetic field, vortices are generated at the pipe entrance and cause the flow rate increase; the flow rate with magnetic field is almost three times as large as that without magnetic field.

5 Conclusion

The three-dimensional air flow caused by the pressure difference $dp$ of $2.8 \times 10^{-8}$ atm. is simulated numerically and the flow rate at an intake where magnets exist is calculated to determine the effect of the magnetic field on the air flow. The air flow caused by only the pressure difference is gentle and seemed to be congestive. Under the magnetic force field, vortices are generated near the magnet by the magnetic force. Vortices disturb the air flow, relieve the flow congestion and increase the flow rate as in two-dimensional simulation.

References


