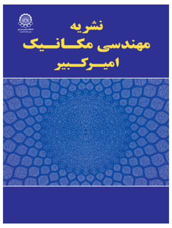

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(4) (2020) 263-266
DOI: 10.22060/mej.2018.14728.5921

Numerical Study of the Effect of the Hall phenomenon on Supersonic flow in Magneto Hydro Dynamic Generator

M. Pourjafargholi[1], G. A. Sheikhzadeh[1]*, R. Maddahian[2]

[1] Department of Mechanical Engineering, University of Kashan, Kashan, Iran
[2] Faculty of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: In the present research, the 2D supersonic airflow in a magneto-hydrodynamic generator is studied numerically and the effect of the Hall effect and the geometry on this flow is investigated. The flow is investigated as a perfect gas, steady and compressible with a low magnetic Reynolds number in a two-dimensional channel with four pairs of electrodes and various geometries including channels with constant cross-section, convergent, divergent and divergent-constant sections as Faraday generator. The results displayed that the Mach angle in the direct channel is less than the other geometries and the output electric power and electrical efficiency and output pressure in the fixed channel are higher than other geometries. Also, Hall effect, which prevents deceleration of the plasma flow due to the magnetic field, reduced the output pressure and joule heating and increased electrical efficiency in all channels. To evaluate the Feasibility of the use of magneto-hydrodynamic generators in aerospace and missile industries, various results of the krypton gas flow and airflow, in particular Joule heating was compared. The comparison is done that if the joule heating of the krypton gas was less and the output electric power and electrical efficiency of this gas was more, it recommends as a proper gas for using in the mentioned industries.

Review History:

Received: 19 Jul. 2018
Revised: 30 Sep. 2018
Accepted: 2 Dec. 2018
Available Online: 30 Dec. 2018

Keywords:

Magneto-hydrodynamic generator
Hall effect
Maxwell equations
Magnetic interaction number
Joule heating

1- Introduction

Over the past few decades, the demand for electricity has risen to an alarming degree exceeding electricity generation. Current power generation methods are not effective enough. Among the new methods of energy conversion is the generation of electrical energy from plasma kinetic energy (ionized gas) in Magneto-Hydro Dynamic (MHD) generators [1]. Due to the relatively low weight of these generators in comparison with conventional generators, in recent years, many suggestions have been made to use them in various devices such as aircraft and spacecraft with supersonic and hypersonic velocities. Of course, the overall design and optimization process of the generator is complex and requires cost, efficiency, size, and technical feasibility considerations. In addition, the Hall effect is also one of the most influential factors in the performance of the MHD generator.

Many experimental and theoretical studies have been conducted in order for the use the MHD generator at speeds greater than Mach number of 4, for example: the empirical research of Bobashev et al. [2-4] as well as Lapushkina et al. [5]. They investigated the effect of electric and magnetic fields on the shock waves produced at the diffuser inlet and the possibility of controlling these waves by the Schlieren system. Their results showed that by increasing the magnetic field, the point of collision of the attached shock waves shifts toward the diffuser inlet, and for effective control of these waves, magnetic fields should be applied to the diffuser inlet. Otherwise, the flow response to the applied field will be lower.

Including numerical activities can be pointed to the work of Kuranov and Sheikin [6]. They examined the control of the Euler flow field at the entrance of the scramjet engine of Ajax hypersonic aircraft and the performance improvement of this engine using the potential of the MHD generator. Their results showed that this generator can be used both to control the position of the oblique shock wave at the engine inlet that leads to improve its performance and to generate electric current. Gaitonde and Poggie [7] also studied Hall effect on the MHD. Their results showed that the potential distribution is symmetrical if there are no Hall effect, ion slip, and axial voltage drop.

As discussed in the research history section, the activities which have been performed on MHD generators have generally been in the Mach numbers of around 4, while numerical or experimental activities have not been done on Mach numbers close to 1 (sound speed). The Mach number range about 4 is related to scramjet engines. In turbojet engines, the velocity of the inlet flow in the combustion chamber must be less than M=1, so it is essential that the supersonic flow is converted to the subsonic flow. The use of MHD generators in these engines, in addition to reducing the air flow velocity at the inlet of the combustion chamber, can also provide a portion of the required electric power of the aircraft.

Definitely, the damages caused by the Hall effect should also be considered. This effect severely prevents plasma flow deceleration induced by the applied magnetic field and reduces electric power generation. However, by selecting a suitable geometry and segmented electrodes can be reduced the effects

*Corresponding author's email: nozar@ssau.ac.ir

Table 1. Comparison of the performance parameters of various types of channels in two modes contain without and with β

	Cross section of the channel					
	Fixed		Divergent		Fixed - divergent	
	β=0	β=0	β=0	β=0.5	β=0	β=0.5
Ma_2	1.36	1.38	1.4	1.61	1.1	1.296
P_2(kPa)	155	152.9	124	92.26	193.8	120.31
T_{max}(K)	643.4	683.5	668.3	825.4	659.7	757.67
$\bar{q}_j$ (MW.m^{-2})	290.6	287.5	390.2	356.7	298.7	282.16
q_j (MW.m^{-2})	422.3	453.2	472.9	520.5	435.3	427.76
$\acute{\eta}_e$	%59.2	%61.2	%54.8	%59.3	%59.3	%60.3

Table 2. Comparison of the performance parameters of air and Krypton in two modes contain without and with β

	Air		Krypton	
	β=0	β=0.5	β=0	β=0.5
Ma_2	1.36	1.38	1.37	1.39
P_2(kPa)	155	152.97	168	163.809
T_{max}(K)	643.4	683.52	895.5	943.03
$\bar{q}_j$ (Mw.m^{-2})	290.61	287.52	205.5	188.79
$\bar{q}$ (Mw.m^{-2})	422.28	453.21	235.5	256.87
$\acute{\eta}_e$	%59.23	%61.18	%53.4	%57.64

of the Hall effect. In order to achieve the maximum power and obtain the variations in flow velocity and reduction of the effects of the Hall effect, it is necessary to examine different geometries of engine inlet for the flow within the Mach number range of about 2. The present study is the first study of the application of these generators in the Mach number range of about 2.

2- Methodology

The governing equations related to the MHD generator include the Navier-Stokes equations plus the electromagnetic source terms, Maxwell's equations and the generalized Ohm's law as follows.

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho \bar{u}_j)}{\partial x_j}=0 \tag{1}$$

Momentum equation:

$$\frac{\partial}{\partial t}\left(\rho \bar{u}_i\right)+\frac{\partial}{\partial x_j}\left(\rho \bar{u}_i \bar{u}_j\right)= -\frac{\partial \bar{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial \bar{u}_i}{\partial x_j}+\frac{\partial \bar{u}_j}{\partial x_i}\right)-\rho \overline{u_i' u_j'}\right]+\bar{F}_L \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial t}\left(\rho C_p T\right)+\rho C_p u_j \frac{\partial T}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T}{\partial x_j}\right) +\frac{\partial}{\partial x_j}\left(\overline{u_i . \tau_{ji}}\right)-\frac{\partial}{\partial x_j}\left(\overline{p u_j}\right)-\frac{\partial}{\partial x_j}\left(\rho C_p \overline{u_j' T'}\right)+\bar{E} \tag{3}$$

The simplified Maxwell's equations:

$$\nabla \times \mathrm{E}=0 \tag{4}$$

The generalized Ohm's law:

$$J=\sigma(E+VB)-\beta(\mathrm{j} \times b) \tag{5}$$

In this paper, Fluent software is used to solve flow equations in the generator. Navier Stokes equations are solved by density based solver the basis of density as implicit. The equations are discretized by the second-order upwind method. To solve the electromagnetic source terms and the potential equation, the code as User Defined Function (UDF) is added to the software.

In the present study, all three models of turbulence models k-ε standard, RNG k-ε, and Realizable k-ε were investigated. According to the results of Zhou et al., RNG k-ε model was selected. Also, the computational grid is selected so that the value of y+ is less than 1 for correct calculation of the velocity and potential gradients. So, the wall functions were not used along the walls.

3- Results and Discussion

The results of the numerical solution of the flow in different channels with Bz=9.5T at two modes of without and with Hall effect equal to β=0.5 are compared together in Table 1.

In Table 1, if the results of the mode of without Hall effect carefully investigate, it can be seen that the most amount of deceleration is in the divergent-fixed channel. Because the flow is supersonic, that compared to the divergent channel is reasonable. Although, the amount of Joule heating of the two-channel (divergent and fixed channels) has not significantly different, but the connection point of two parts of divergent and fixed of the channel causes energy loss. So that carefully at the results, it can be received that oblique shock wave with Mach=1.6 in divergent-fixed channel earlier than fixed channel has occurred. But, the electric power and electrical efficiency in the fixed channel are higher than the rest. On the other hand, the amount of Joule heating in divergent-fixed and fixed channels do not much difference with each other too.

Eventually, the difference of generator performance such as joule heating and electric power generation has investigated for the working gases of air and krypton in the fixed channel and the results listed in Table 2.

4- Conclusions

Based on the investigation, the results include the following cases:

1. In the mode of with a magnetic field (Bz=9.5T), the velocity flow in the outlet of the fixed, the divergent, the divergent-fixed channels decreases up to 1.36, 1.4 and 1.16 respectively.

But if Hall effect, as well as Bz, take into account, the velocity in these channels outlets reduces up to 1.38, 1.61

and 1.296 respectively and besides that, the Mach number distribution becomes asymmetrical. Also, it should also be noted that maximum electrical efficiency, electric power produced and the output pressure are related to the fixed channel. So, it can be concluded that a channel with constant cross-section is suitable as the MHD generator for use in the turbo-ramjet engine.

2. The results showed that if Krypton gas is used, electric Power and electrical efficiency will be less in Compared to air.

References

[1] M. Pourjafargholi, G. Sheikhzadeh, and R. Maddahian. “Numerical investigation of the effect of the geometry and boundary conditions on Supersonic flow in a 2D MHD channel.” Modares Journal of Mechanical Engineering 17.8 (2017): 301-312 (in Persian).

[2] S.V. Bobashev, E. A. D’ yakonova, A. V. Erofeev, T.A. Lapushkina, V. G. Maslennikov, S. A. Poniaev, A. A. Sacharov, and R. V. Vasil’eva. “Shock tube facility for MGD supersonic flow control.” 21st AIAA Aerodynamic Measurement Technology and Ground Testing Conference, 2000.

[3] S. V. Bobashev, A. V. Erofeev, T. y. A. Lapushkina, S. A. Poniaev, R. V. Vasil’eva, and D. M. Van Wie, “Experiments on MHD control of attached shocks in diffuser.” 41st Aerospace Sciences Meeting and Exhibit, 2003.

[4] S. Bobashev, A. Erofeev, T. Lapushkina, N. Mende, S. Poniaev, V. Sakharov, R. Vasilieva and D. Van Wie. “Recent results on MHD flow control at Ioffe institute.” 14th AIAA/AHI Space Planes and Hypersonic Systems and Technologies Conference, 2006..

[5] T. Lapushkina, S. Bobashev, R. Vasil’eva, A. Erofeev, S. Ponyaev, V. Sakharov and D. Van Wie. “Influence of electric and magnetic fields on the shock wave configuration at the diffuser inlet.” Technical Physics 47.4 (2002) 397-405.

[6] A. Kuranov, and E. Sheikin. “Magnetohydrodynamic control on hypersonic aircraft under AJAX concept.” Spacecraft and Rockets 40.2 (2003) 174-182.

[7] D. V. Gaitonde, and J. Poggie. “Elements of a numerical procedure for a 3-D MGD flow control analysis.” 40th AIAA Aerospace Sciences Meeting and Exhibit, 2002.