# Experimental Study On The Effects Of Transversally Shaped Configuration Of The Magnet Field Upon The Output Performance Of An MHD Generator

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# EXPERIMENTAL STUDY ON THE EFFECTS OF TRANSVERSALLY SHAPED CONFIGURATION OF THE MAGNETIC FIELD UPON THE OUTPUT PERFORMANCE OF AN MHD GENERATOR*

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## Abstract

Effects of applying the transversally shaped configuration of the magnetic field[1-2] upon the output performance of a Faraday type MHD generator were investigated experimentally by using shock heated plasmas seeded with $K_2CO_3$. The strength of the magnetic field beyond the boundary layer region of electrodes was sharply reduced by immersing mild steel bars both within the electrode and insulator walls made of an acrylic resin

It was observed that the apparent conductivity, the output power, the effective internal resistance and the anode potential drops were markedly improved in comparison with those of the MHD generator with the convertional uniform distribution of the magnetic field. It could certainly be said that these effects were due to the reduction of Hall's effect within the cold boundary layers and also due to the guiding effect for the output current toward the electrode by the transverse component of the magnetic field.

## I. Introduction

The output performance of an open cycle MHD generator for long duration operations is severly deteriorated by nonuniform electrical conduction phenomena due to Hall's effects and steep changes of the conductivity within boundary layers.[3-6] The improvement of the output power density through the suppression of these so-called boundary layer losses is very important problems to be solved in order to reduce the size both of the MHD generator channel and the superconducting magnet for a commercial scale MHD power plant.

The authors have proposed[1-2] from the theoretical point of view that reducing the applied magnetic field strength in the region of electrode boundary layers may be one of the most effective means for achieving the above mentioned purposes.

In order to verify the authors proposals, experimental investigations were performed in the present work. Experiments were carried out by employing shock tubes, because it was required that troubles and difficulties arising from the thermal damage on probes, electrodes and channel walls had to be avoided as far as possible for the comparison between the shaped field configuration (SFC) type and the uniform field configuration(UFC) type of the MHD generator.

The shaped field configuration was approximately realized by immersing the mild steel bars with appropriate cross sectional forms each within the electrode and insulator walls made of an acrylic resin. The channel without these bars was also constructed as a model for the conventional UFC type of the MHD generator. Two steel bars within the insulator walls of the SFC type channel intensify the magnetic field strength in the center region of the channel and the other two bars within the electrode walls sharply reduce the magnetic field component $B_z$ which is parallel to the electrode surface. These two side bars produce at the same time the magnetic field component $B_y$ normal to the electrode surface, which may also be effective for increasing the effective conductivity as discussed in the next section.

## II. Brief Discriptions on the Effects of the SFC

Two effects for reducing the boundary layer losses could be expected in the SFC type of the MHD generator. The first is the minimization effect of the nonuniformity factor[3] given by the equation (1)

$$G = \langle\sigma\rangle\langle\frac{1}{\sigma}\rangle + \langle\sigma\rangle\langle\frac{\beta_z^2}{\sigma}\rangle - \langle\beta_z\rangle^2 , \qquad (1)$$

where $\sigma$ is the local electrical conductivity, $\beta_z$ is Hall's parameter relating to the magnetic field component $B_z$ and < > is the spatial average in the direction normal to the electrode surface.

Here, if the condition;

$$\beta_z \propto \sigma \text{ or } B_z \propto n_e \qquad (2)$$

could be realized locally, then

$$G = \langle\sigma\rangle\langle\frac{1}{\sigma}\rangle \quad . \qquad (3)$$

So that the nonuniformity factor does no longer depend upon Hall's effect. It can easily be shown that the local Hall's current disappears completely under the ideal configuration of the magnetic field given by the equation(2) and that the output power density $\hat{p}$ increases with the spuare of the magnetic field $\langle B_z\rangle^2$, being irrespective of the electrode temperature and the component $B_y$[1].

The second effect is the improvement of the local electrical conductivity tensor due to the appearance of the magnetic field component $B_y$

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normal to the electrode surface. The conductivity tensor including Hall's parameters $\beta_y \equiv \mu B_y$ and $\beta_z \equiv \mu B_z$ is given by

$$\|\sigma\| = \frac{\sigma}{1+\beta_y{}^2+\beta_y{}^2} \begin{bmatrix} 1 & -\beta_z & \beta_y \\ \beta_z & 1+\beta_y{}^2 & \beta_y\beta_z \\ -\beta_y & \beta_y\beta_z & -\beta_z{}^2 \end{bmatrix} \quad (4)$$

In the region near electrode of the SFC type channel, $\beta_z$ is decreased and $\beta_y$ is increased due to the inclination of the magnetic lines of force as shown in Figure 1, so that the effective element $\sigma_{yy}$ for a Faraday type becomes much greater than in case of the UFC type channel, where $\beta_y \equiv 0$.

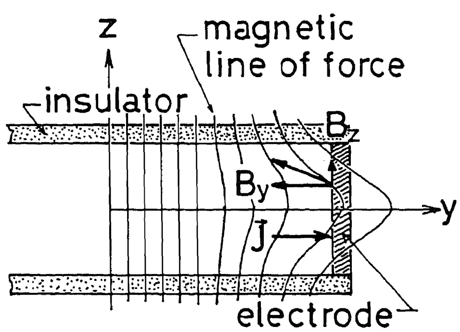


Figure 1 Guiding effect of the magnetic field component $B_y$ on the out-put current near electrodes

Such a guiding effect of the field lines for the out-put current could also be expected each in the declined[7] and the side wall electrode[8] configurations.

Since comparisons among these three ideas are out of the scope of the present work, we used rectangular Faraday's type channels with segmented flat electrodes in course of the present experiments, which were carried out under two different experimental conditions.

## III. Discriptions of Experiments

### 3-1 Test-I

The Test-I was conducted in a shock tube MHD facility shown in Figure 2 at the Tokyo Institute of Technology. The details of the shock tube are given in ref. 9. The experimental conditions are listed in Table 1.

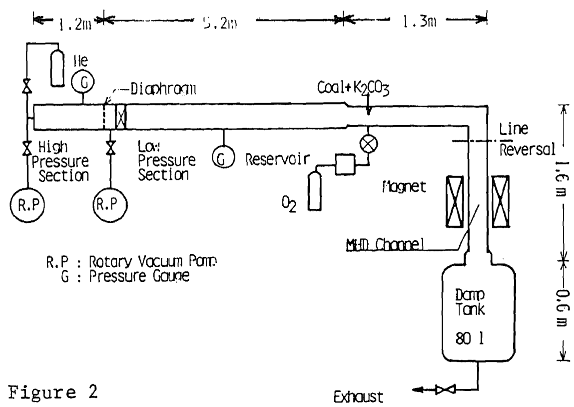


Figure 2
Shock tube MHD facility for Test-I

| | | |
|---|---|---|
| Shock tube | | |
| High pressure section | $H_e$ | 13 atm |
| Low pressure section | $O_2$ | 15 Torr |
| Coal input | | 0.4 g |
| $K_2CO_3$ input | | 0.2 g |
| Plasma | | |
| Stagnation gas pressure | | 2.6 atm |
| Stagnation gas temperature | | 2800 K |
| Gas velocity | | 1062 m/sec |
| Mach number | | 4.5 |
| External magnetic field | | |
| Flux density | | 0.50,1.06,1.95 Tesla |
| MHD channel | | |
| Type | | Faraday |
| Height | | $7.0\times10^{-2}$ m |
| Width | | $4.0\times10^{-2}$ m |
| Length | | 0.45 m |
| Electrode pair | | 21 |
| Pitch of segmentation | | $1.0\times10^{-2}$ m |

Table 1 Experimental Condition for Test-I

The working gas was the shock ignited coal combustion plasma seeded with $K_2CO_3$. The SFC type of the Faraday MHD channel with mild steel bars immersed within four side walls is shown in Figures 3-(a) and (b). The magnetic field distribution obtained by this means is shown in Figure 4.

The MHD channel without mild steel bars was also constructed as a model for the UFC type generator. The externally applied magnetic field $B_{ext}$ was same for two channels. The spatially averaged magnetic field strength acting on the plasma in the SFC channel was slightly less than that in the UFC channel. This is seen from the data of the open circuit voltage vs. $B_{ext}$ shown in Figure 5.

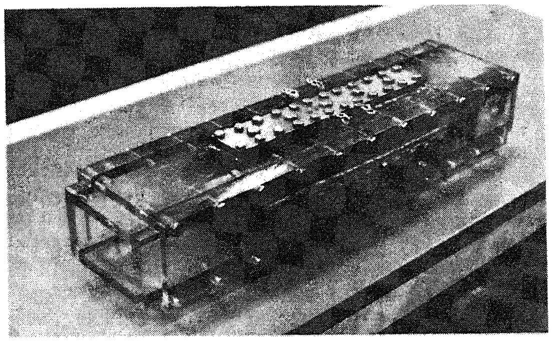

Figure 3-a SFC type MHD generator channel

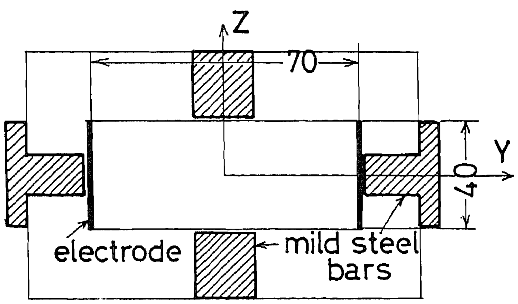


Figure 3-b Cross section of the SFC type MHD channel

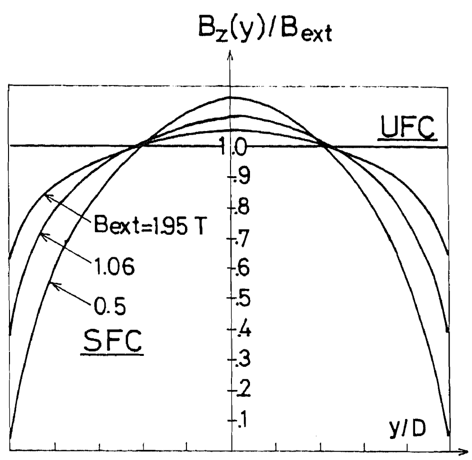


Figure 4 Distribution of the magnetic field component $B_z$ in the SFC type MHD channel

Twenty pairs of copper plate electrodes with the area 7x40 $mm^2$ and the thickness 0.5 mm was fixed to the two dectrode walls with a segmentation pitch 10 mm. The electrode height was 70 mm and the cross sectional area of the channel was 40 x 70 $mm^2$.

The output voltage, the current and the potential distrubution across the channel were measured under the load conditions each of $R_L$=2, 50 and ∞ ohms, restpectively.

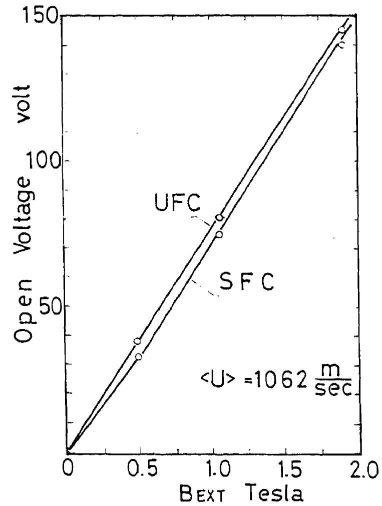


Figure 5 Open circuit voltage

The measured potential distribution in the Test-I experiment is shown in Figure 6. It is to be noted that the marked reduction of the anode potential drop was realized as a consequence of the SFC type of the applied magnetic field.

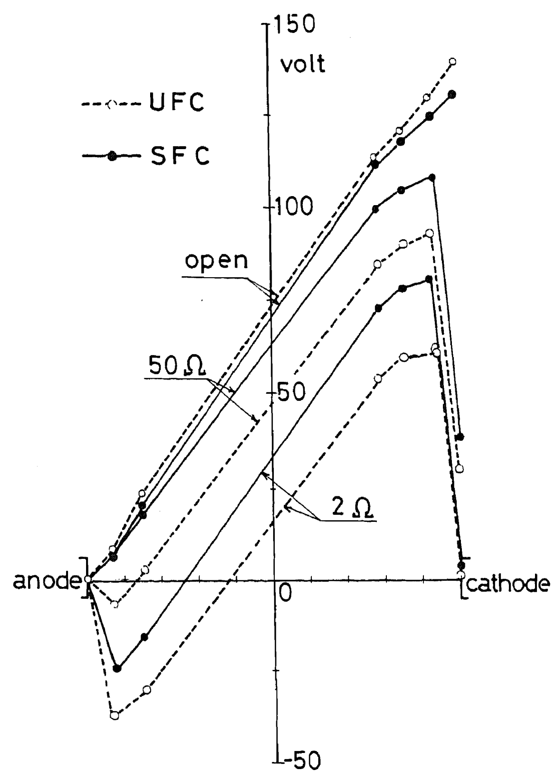


Figure 6 Potential distributions each in the SFC and the UFC type MHD channels

The apparent conductivity, which was deduced from the measured data by using the following equation :

$$\sigma_{app} = \frac{\langle J_y \rangle}{\langle E_y \rangle - \langle VB \rangle} = \frac{\langle \sigma \rangle}{G} \qquad (5)$$

and the output power density are shown each in Figure 7 and 8, respectively.

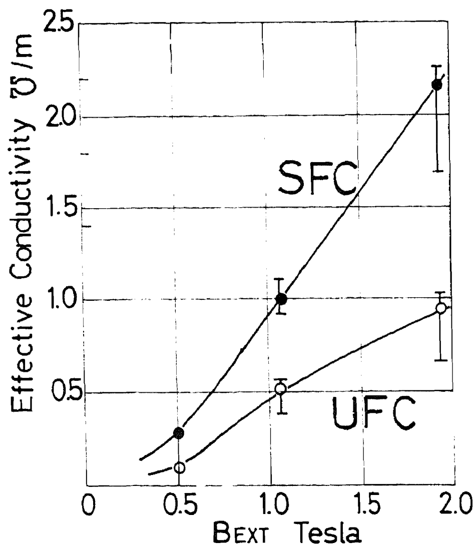


Figure 7 Apparent conductivity measured each in the SFC and the UFC type MHD channels

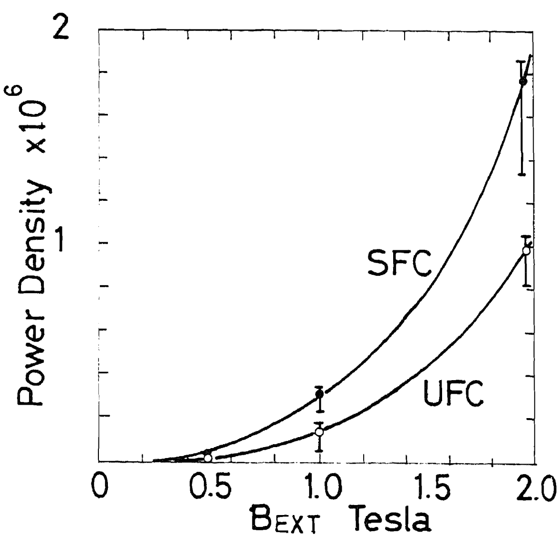


Figure 8 Output power density vs. the externally applied magnetic field each in the SFC and the UFC type MHD channels

It is shown that the apparent conductivity and the output power density have been improved by about 50-100 % compared with those of the conventional MHD generator with a uniform magnetic field distribution.

The apparent conductivity under the diffuse conduction mode decreases with increasing the magnetic field strength in the UFC case and is approximately independent of the field strength in the SFC case as predicted by the second relationship of the equation (5). However, the measured apparent conductivity increases against the magnetic field strength. Thus it seems that the present experiment has verified the effectiveness of the SFC type of the magnetic field distribution even for the case of the arc mode operation.

## 3-2 Test-II

Using the shock tube MHD facility recently introduced at Hokkaido University shown in Figure 9, the secnd test was carried out in order to collect more sufficient data of the output power and the apparent conductivity.

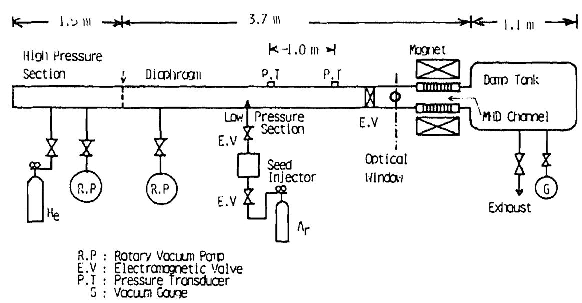


Figure 9 Shock tube MHD facility employed for Test-II

| | | |
|---|---|---|
| **Shock tube** | | |
| High pressure section | $H_e$ | 14 atm |
| Low pressure section | $A_r$ | 15 Torr |
| $K_2CO_3$ | | 0.1 g |
| **Plasma** | | |
| Gas pressure | | 0.8 atm |
| Gas temperature | | 2500 K |
| Gas velocity | | 1070 m/sec |
| **MHD channel** | | |
| Type | | Faraday |
| Height | | $6.0 \times 10^{-2}$ m |
| Width | | $2.0 \times 10^{-2}$ m |
| Length | | 0.25 m |
| Electrode pair | | 11 |
| Segmentation pitch | | $1.0 \times 10^{-2}$ m |

Table 2 Experimental Condition for Test-II

Argon seeded with $K_2CO_3$ powder was used in order to realize an equilibrium plasma with relatively high Hall's parameter even under a low magnetic flux density employed in the Test-II. The gas was heated up to about 2500 K by an incident shock. The experimental conditions are listed in Table 2.

The shaped configuration of the magnetic field was realized by similar method employed in the Test-I. The MHD channel has a cross sectional area of 20 x 60 $mm^2$ and 11 pairs of segmented copper plate electrodes with the pitch 10 mm.

The spatially averaged magnetic field strength of the SFC type channel was slightly higher than that of the UFC type channel in the case of Test-II.

The load-power characteristics obtained from two types of channels are shown in Figure 10.

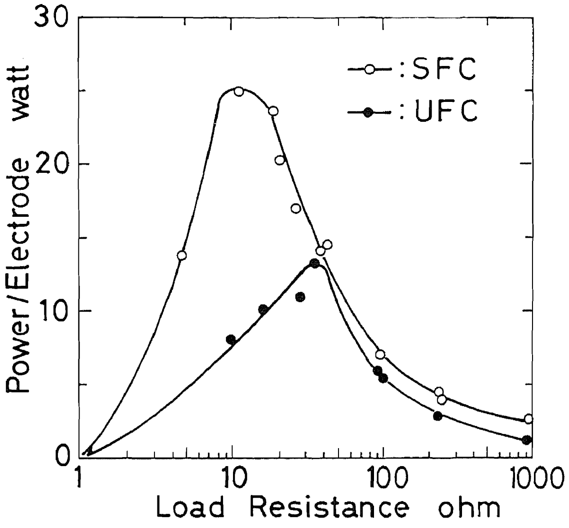


Figure 10 Load-Power characteristics each of the SFC and the UFC type of the MHD generator

The maximum power densities each of the SFC type and the UFC type channels are 2.95 $MW/m^3$ and 1.58 $MW/m^3$, respectively. The matching load resistance for the SFC case is also reduced by a factor of about 3. The apparent conductivity calculated by equation (5) is given in Figure 11, which also shows that the proposed MHD generator exhibits a cospicuously improved performance.

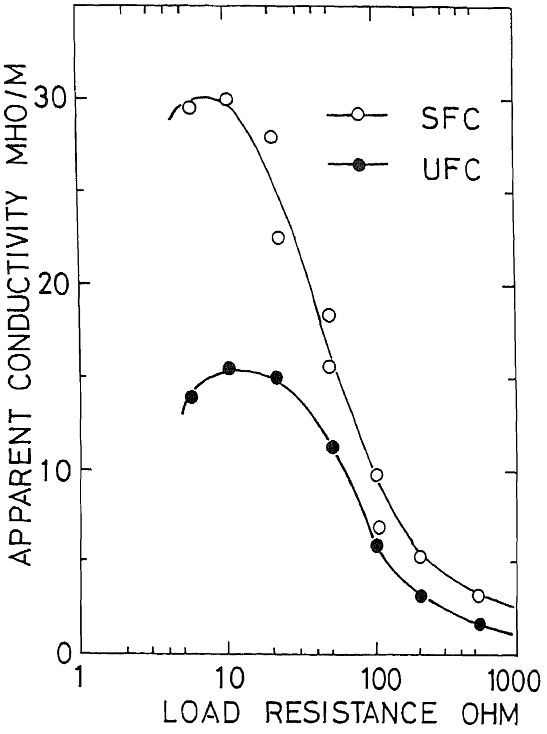


Figure 11 Apparent conductivity each of the SFC and the UFC type MHD generator

## IV. Discussions and Conclusions

The output performance of Faraday's type MHD generator with a new type of the applied magnetic field configuration was experimentally investigated by using shock tubes. It was observed that the output power, the apparent conductivity and the potential drops at the anode were markedly improved by a factor about 2 both due to reducing $\beta_z$ and increasing $\beta_y$ in the region near electrodes.

The present data were mostly obtained under the arc mode operation. Experimental investigations on the performance of the SFC type MHD generator under the diffuse mode and the micro arc mode are being carried out by a newly constructed large shock tunnel MHD facility.

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