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RESULTS AND COMPARISON OF HALL AND DW DUCT EXPERIMENTS*

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Abstract
Experimental data from recent tests of a 45°
diagonal wall duct are presented and compared with
the results of a similar Hall duct. The results obtained here
it is shown that while the peak power density of the two devices is approxi-
mately equal that the diagonal wall duct produces
greater total power output due to its ability to
to better utilize the available magnetic field.

I. Introduction
In this paper the results of recent tests
utilizing a diagonal wall (DW) MHD duct with a
diagonalization angle of 45° are presented and
compared with the results of a similar Hall duct.
The experiments were run in the NASA-Lewis high
magnetic field strength, liquid-neon-cooled
cryomagnet facility (ref. 1), which has been
modified to run under vacuum exhaust through the
addition of a large vacuum tank (ref. 2).

This tank allows evacuation of the system to
approximately 2 psia and it was located within
the magnet bore tube so as to best approximate
the area ratio of the Hall duct over the active
region of the Hall duct. The location of the two
ducts relative to the centerline of the magnet
and their internal outlines are shown in figure 1.

III. Power Takeoff Location

It is noted from figure 1 that the power pro-
ducing region for the DW duct is considerably
larger than that of the Hall duct. This is the
result of the maximum power location of the power
loads for the single load resistance configuration
used in these experiments. In figure 2 the axial
profile of Hall voltage as a function of distance
from the magnet centerline is shown. In both
curves the load was connected across the first
and last electrodes. This power takeoff location
leads to regions of power dissipation, as noted
by the negative slope of the voltage curve at the
front and rear of the ducts. Therefore to obtain
the maximum power output with a single load, the
power takeoffs must be located at the front and
rear min-max points of the voltage curve. From
figure 2 it is seen that these points cover a
much larger portion of the magnetic field region
for the DW duct than for the Hall duct.

The reason for the above difference is seen
from the equation for the Hall electric field
(ref. 3)

\[ E = \frac{(1 + \theta)}{\alpha A} \times \frac{(1 - \theta)(\theta + \phi)}{2} \times \frac{u}{1 + \phi} \]

where \( \theta \) is the cross sectional area of the duct
and \( u \) is the local gas velocity, \( B \) is the
magnetic field intensity, \( \phi \) is the electrical
conductivity, \( \theta \) is the Hall parameter, \( A \) is the
dimensionless effective voltage drop, \( I \) is the
load current and \( \theta \) is the tangent of angle
between the direction of \( u \) and the plane of the
electrode, i.e., \( \theta = 0 \) for Hall duct and \( 1 \) for
45° DW duct. Therefore,

\[ E_{\text{Hall}} = \frac{1 + \theta}{\alpha A} \left[ \frac{1}{1 - \theta} \right] - \theta \left[ 1 - \theta \right] u \]

\[ E_{\text{DW}} = \frac{1 + \theta}{2 \alpha A} \left[ \frac{1}{1 - \theta} \right] - \theta \left[ 1 - \theta \right] u \]

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The min-max point occurs for \( E_x = 0 \). Comparing equations 2 and 3, it is seen that the \((1 + \beta)\) multiplier of the EMF term for the DW duct is greater than the \(\alpha\) multiplier for the Hall duct. Therefore, other things being equal, the inflection point for the DW duct will occur at a lower \( \phi \) field than for the Hall duct. Hence a greater portion of the magnetic field region can be used by the DW duct with a single load resistance.

Based upon the above considerations, the load resistance was connected between electrodes 12, 13, 14 to electrodes 42, 43, 44 for the DW duct and between electrodes 36, 39, 40 to electrodes 90, 91, 92 for the Hall duct.

IV. Load Considerations and Power Output

Figure 3 shows the voltage-current relationships for the Hall and DW duct. The slope of these curves is the total internal impedance of the device. From these curves it is found that the internal impedance is 19.8 Ohm and 29.9 Ohm for the Hall and the DW duct, respectively. This difference in impedance can be shown to be consistent with theory. The theoretical value of the impedance from equation 1 is taken from the first term on the right of equation 1 to be

\[
R = \frac{1}{2} \frac{1}{\alpha} \int_0^L \frac{1 + \beta}{\alpha} \; dx
\]

where \( L \) is the active length of the duct.

To first order the plasma properties of the two devices are equal (low power extraction in both devices, i.e., max. enthalpy extraction \( = 3.5 \) percent) and therefore from equation 4 their impedances should ratio approximately like

\[
\frac{R_{\text{Hall}}}{R_{\text{DM}}} = \frac{L_{\text{Hall}}}{L_{\text{DM}}} = \frac{2(37.5 \text{ cm})}{2(51.75 \text{ cm})} = 1.45
\]

where the active lengths were obtained from figure 1. This result compares favorably with that obtained from the \( V-I \) curves, i.e.,

\[
\frac{R_{\text{Hall}}}{R_{\text{DM}}} = \frac{29.9 \text{ Ohm}}{19.8 \text{ Ohm}} = 1.51
\]

In the discussion to follow, all of the data was taken with a load resistance of 11.5 Ohm while for peak power output one wants to match the internal impedance. The reason for the choice of 11.5 Ohm was the present voltage isolation limitation upon some of the instrumentation which would be exceeded at the upper limits of the magnetic field strength (6 Tesla). This clearly favors the performance of the DW duct since it is a lower impedance device.

In figure 4 the power output of the two devices is shown as a function of the square of the B-field. It is seen, as has been previously observed over a broad range of Hall duct area ratios (ref. 4), that the power output of the Hall duct is linear with the square of the magnetic field. This is also true of the DW duct up to approximately 4 Tesla beyond which the rate of increase in power output with the square of the magnetic field decreases. This characteristic was also observed for Hall ducts when the pressure ratio across the duct was insufficient to provide shock free performance throughout the duct (ref. 4). For the circled points of the DW duct curve the scatter in the pressure data was sufficient that the presence of a shock could not be detected. However, for the square point labeled "Run 564" (the 4 square points on figure 4 represents runs made at the fuel rich oxygen/fuel weight ratio of 6/1) the presence of a shock was detected.

In figure 5 the time dependence of the Hall voltage is plotted for Run 564. It is seen that at a time of between 3.2-3.4 sec there is an abrupt decrease in the Hall voltage. In figure 6 the axial pressure profile is plotted. The curve drawn through the circled points represents the profile just prior to the Hall voltage decrease. In this case no abrupt increase in pressure is observed although the adverse pressure gradient at the rear of the duct could possibly indicate a weak shock. The square points represent the pressure profile after the Hall voltage decrease and definitely indicates the presence of a shock in the neighborhood of electrode 24. This can also be seen from the Hall voltage axial profile shown in figure 7. In this figure shock location corresponds to an "abrupt" change in the slope of the voltage profile in the neighborhood of electrode 24.

The time dependency for the creation of the shock is due to the buildup of back pressure in the vacuum tank during the run (the vacuum pump is too small to maintain vacuum pressure while the combustor is running). In the early stages of the run, it is suspected that the shock is located at the exit of the diffuser. When the back pressure increases to a point where there is insufficient pressure ratio across the duct then the shock moves through the constant area diffuser and downstream portion of the DW duct into the conical portion of the duct (upstream of electrode 33) where it can stably attach for the remainder of the run.

The point labeled "Run 564" on figure 4 is the value prior to the shock induced decrease in the Hall voltage and represents the largest power extraction yet attained in our facility representing 275 kW which is 3.5 percent of the input enthalpy. Also from figure it is noted that the voltage sustained without electrical breakdown was 80 V/insulator. This represents a substantial increase over the 50 V/insulator value observed for a Hall duct with similar segmentation ratio (ref. 1). The Hall duct discussed in the present paper has a segmentation ratio 1/2 that of the DW duct and no electrical breakdown has been observed in this duct.

In figure 8 the axial profile of power density for the Hall and DW duct is shown. The interesting point is that the peak power densities are nearly equal and therefore the higher power output of the DW channel is primarily due to its better utilization of the magnetic field in the end regions.
V. Concluding Remarks

Specific conclusions that may be drawn from the comparison of the DW and Hall ducts studied in this paper is that:

1. Singly loaded DW ducts can utilize more of the magnetic field region than can Hall ducts.

2. Hall ducts are higher impedance devices.

3. Although interelectrode electrical breakdown was not specifically studied for the DW duct voltages of 90 V/insulator were obtained with no breakdown. This is substantially higher than the 50 V/insulator which was previously observed for a Hall duct of similar segmentation ratio.

References


Figure 1. - Interior cross sections of Hall and DW duct.

Figure 2. - Hall voltage profiles for determining power takeoff location.
Figure 3. - Current voltage diagram.

Figure 4. - Power output versus B-field squared.
Figure 5. - Hall voltage as a function of time.

Figure 6. - Axial pressure profile.
Figure 7. - Axial hall voltage profile.

Figure 8. - Axial power density profile.