INSTITUTE FOR AEROSPACE STUDIES

UNIVERSITY OF TORONTO

SEMI-ANNUAL REPORT

on

OPERATION OF AN MHD POWER GENERATOR

for the period

June 1, 1966 to December 1, 1966

prepared by

Spacecraft Technology Division
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

under the terms of
Grant NGR 52-126-012

UTIAS

submitted by

Stanley J. Townsend
Institute for Aerospace Studies
University of Toronto

March 1, 1967

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SUMMARY

The graphite heater has been heated up to a few hundred degrees above room temperature. This has proved the integrity of the electrical system and the lack of short circuits of the electrodes against the rest of the graphite heater. Heating to temperatures near the oxidation limit of graphite could not be attempted until the heater could be evacuated. This was attempted by pumping the vacuum sphere down to 20 Torr and then cracking the upstream valve until a very faint air flow could be heard. Even this flow proved too large since about two cubic feet of lampblack were pulled downstream. The lampblack is now being removed completely and will be replaced by graphite felt. Enough felt should be on hand by April to enable us to take the heater up to about 1000^{o}K. Complete thermal insulation should be possible by late May, 1967.

The large electromagnet facility will be operating well before the heater. The coils are nearing completion and should be installed in March. The cooling circuit will also be connected in March.

The seeding mechanism has been designed to allow any seed of the Cs, NaK, K_2CO_3 or KOH family to be used interchangeably. It is now being fabricated in the machine shop. Discussions with the MHD Power Generation group at the Institüt für Plasmaphysik have given us much valuable advice on how to obtain uniform seeding rates from random vaporization of seed in the injection tube.

The initial channel is now being fabricated out of alumina brick and stainless steel welded box sections. Six equal sections totalling two meters in length have been fabricated and are awaiting the installation of tungsten electrodes. Cold flow tests and boundary layer growth tests will be run at M = 0.8 during March, 1967.

1. INTRODUCTION

This report is the second semi-annual report written under Grant NGR 52-026-012. It covers the period June 1, 1966 to December 1, 1966. This grant is supervised under the guidance of Mr. N. John Stevens, Spacecraft Technology Division, Lewis Research Center, National Aeronautics and Space Administration. The grant is for the investigation of the operation of a large, inert-gas, magnetogasdynamic power generator with specific emphasis on low-pressure operation.

This research is co-sponsored with NASA. Equipment costs for the facility are being met by research grants from the Defence Research Board and the National Research Council of Canada.

Scientific Personnel

Stanley J. Townsend, Assistant Professor
B. Grace, Research Assistant*
C. H. Hersom, Research Assistant*
C. Yeh, Research Assistant*
G. Hrycko, Summer Student+
J. Manning, Summer Student

* M. A. Sc. students
\+ terminated September 15, 1966

2. INERT-GAS GRAPHITE HEATER - C. Hersom

Early in September, 1966, a subsonic nozzle was fashioned out of 1" thick graphite plates and contoured internally to reduce the 6 1/4" diameter outlet pipe from the heater to the 2" x 4" channel dimensions. The incorporation of this into the heater completed its assembly, and the graphite felt insulation for the top was installed.

The 112 1/2 KVA transformer which powers the heater has been connected up and bus hars installed to carry the large current to the heater. Special water-cooled clamps to connect the bus bars to the graphite heater elements were designed and installed. The entire heater cooling system is completed so that the heater may be operated safely.

The optical pyrometer has been installed and will be used to monitor heater temperature and provide a safety cut-out on the transformer.

The argon supply piping has been completed using six-inch pipe running from a tank farm to the heater. The high and low pressure regulators which make up the argon control section are on hand and the high pressure manifold is being designed for about 25 cylinders.

Carbon raschig rings for the downstream heat exchanges have arrived.

A temporary connection has been made to the vacuum sphere in order to evacuate the heater to prevent oxidation during heat-up. The system has been pressure tested to satisfaction.

More difficulties have arisen with the heater than had been anticipated. Pumping down under vacuum resulted in some of the lampblack thermal insulation being drawn downstream through the vacuum piping. The possibility of this had been foreseen and was to be guarded against by evacuating the heater very slowly. While this is possible in theory, in practice it has turned out to be far too much trouble to take the pressure down slowly enough. Accordingly, all the lampblack will be removed within a few weeks and replaced by graphite felt. This will be costly (about $6000 vs $150 for the lampblack) but our aim is an easily operated facility that does not have to be babied along.

3. SEEDING MECHANISM - C. Yeh

From the curves of mass flow variation with static pressure in the MHD channel for operating conditions permitted by stagnation pressure limitation (see Figure 1), curves of volume flow rate for five different seeding materials have been plotted (see Figure 2).

A seed injection system that can cover the argon mass flow rate from zero to 3 kg/sec has been designed (see Figure 3). It incorporates an end-welded stainless steel bellows which is sealed in a vacuum-tight steel container. The bellows is compressed by a push rod from a linear actuator. The linear actuator is composed of a worm-gear speed reducer and shunt-wound motor whose speed can be varied according to the seeding rate. The output of the worm gear turns an 18 thread-per-inch screw which advances a nut on which the push rod is fastened. The seeding material fills the interior of the bellows. Provisions are made at one end of the bellows for evacuating the interior and the suction of seed from the reservoir. A pressure-equalizing line is inserted to maintain the pressure in the steel cylinder container and the top of the graphite heater approximately equal. This procedure reduces the force required to compress the bellows. The variable speed motor chosen will cover the entire range of operation. However, two different sizes of bellows are used; one works in the range up to 1 kg/sec and the other from 1 to 3 kg/sec, of argon flow. This allows higher sensitivity and thus greater accuracy. The design is now complete and construction has started; preliminary seeding experiments are expected to begin in April.

4. POWER GENERATION CHANNEL - C. Hersom

Materials to build a rough alumina channel have arrived and we have started assembly. The channel will be assembled in 30cm (12 inch) sections to facilitate construction and experimentation as the sections may be readily interchanged to investigate axial variations in performance using only one fully instrumented section before we go ahead and build a full scale machine.

Early tests on the channel will entail cold flows to determine boundary layer build-up down the duct and the warm flows (1000°C) to test structural properties. These tests will be started about April.

5. ELECTROMAGNET FACILITY - B. Grace

The design for the electromagnet (other than the pole pieces) was finalized giving 1.7 Tesla over a gap 15cm x 25cm x 125cm (6 in. x 10 in. x 50 in.) long. The material used was mild steel flame cut in twenty-five two-inch thick slabs. A support assembly was then designed and constructed to allow the magnet to be rolled aside to facilitate work on the MHD channel.

Using a computer program, the design of the magnet pole pieces in fine detail was accomplished. The criteria were to produce a high constant field over a large cross section of the gap with minimum saturation and fringe effects. The optimum design is shown with computer predicted fields in Figures 4, 5 and 6. The magnet is expected to produce 1.7 Tesla within 0.5% over a 5cm x 10cm (2 in. x 4 in.) channel, and within 3% over a 8cm x 15cm (3 in. x 6 in.) channel, with a 1m (40 in.) useful length of field. The pole pieces may be replaced if a smaller constant field over a larger area is required.

The electrical design of the magnet was finalized, employing coils of entruded aluminum conductor 1.15cm (0.45 in.) square o.d. by 0.63cm (0.25 in) circular I.D. The magnet runs at 137 volts per coil and 834 amps., and is powered by a bank of thirty 12-volt heavy duty batteries already installed. The expected ohmic dissipation is 114 kW per coil at full power. A water cooling system was designed employing a manifold system which restricts the coil temperature rise to 22°C (40°F). The coils themselves are being fabricated. Large steel beams were installed to reinforce the laboratory floor, and the magnet body was assembled, awaiting the coils and pole pieces.

6. PROBE DIAGNOSTICS - B. Grace

A review of the literature was made to determine feasible methods of designing probes or sensing electrodes for conductivity measurements and for mapping current paths. Initial steps have been taken in the design of a suitable sensing electrode. Problems such as heat transfer from the flow and electrical insulation at high temperatures are being considered. Current thinking and the experience of other workers in the field suggests that a ceramic insulated tungsten sensing electrode will be a good starting point. A simple probe design which may permit ignoring sheath and emission effects has been proposed. Possible electronic circuits for measurement are being considered; a straightforward technique for initial conductivity mappings has been suggested.

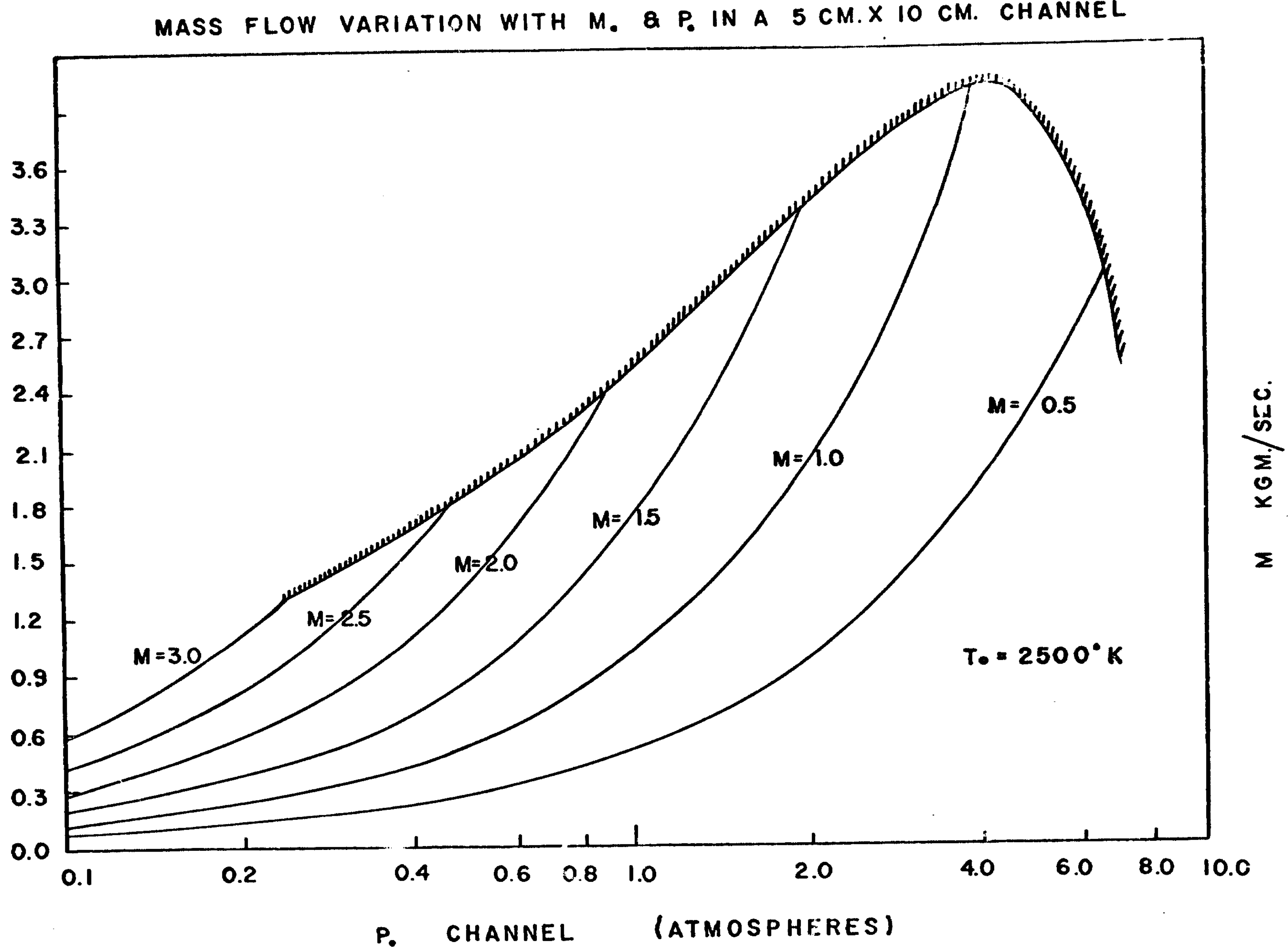


FIG. 2.1 MASS FLOW VARIATION WITH STATIC PRESSURE IN M. H. D. CHANNEL FOR OPERATING CONDITIONS PERMITTED BY STAGNATION PRESSURE LIMITATION

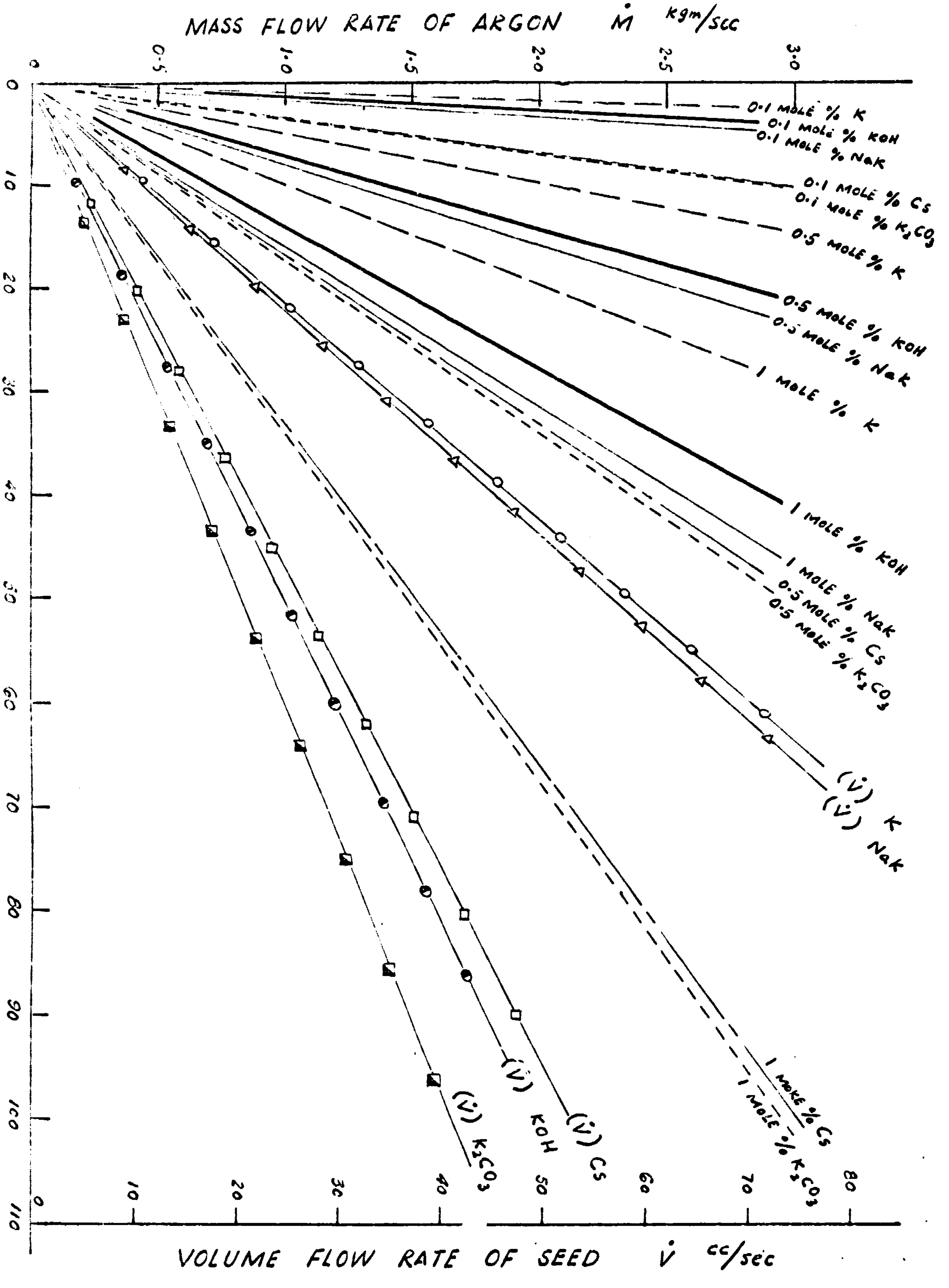

MASS FLOW RATE OF ARGON Ṁ kgm/sec
0
0.5
1.0
1.5
2.0
2.5
3.0
0.1 MOLE % K
0.1 MOLE % KOH
0.1 MOLE % NaK
0.1 MOLE % Cs
0.1 MOLE % K_2CO_3
0.5 MOLE % K
0.5 MOLE % KOH
0.5 MOLE % NaK
1 MOLE % K
1 MOLE % KOH
1 MOLE % NaK
0.5 MOLE % Cs
0.5 MOLE % K_2CO_3
($\dot{V}$) K
($\dot{V}$) NaK
1 MOLE % Cs
1 MOLE % K_2CO_3
($\dot{V}$) K_2CO_3
($\dot{V}$) KOH
($\dot{V}$) Cs
MASS FLOW RATE OF SEED Ṁ gm/sec
0
10
20
30
40
50
60
70
80
90
100
110
VOLUME FLOW RATE OF SEED $\dot{V}$ cc/sec

FIG. 2

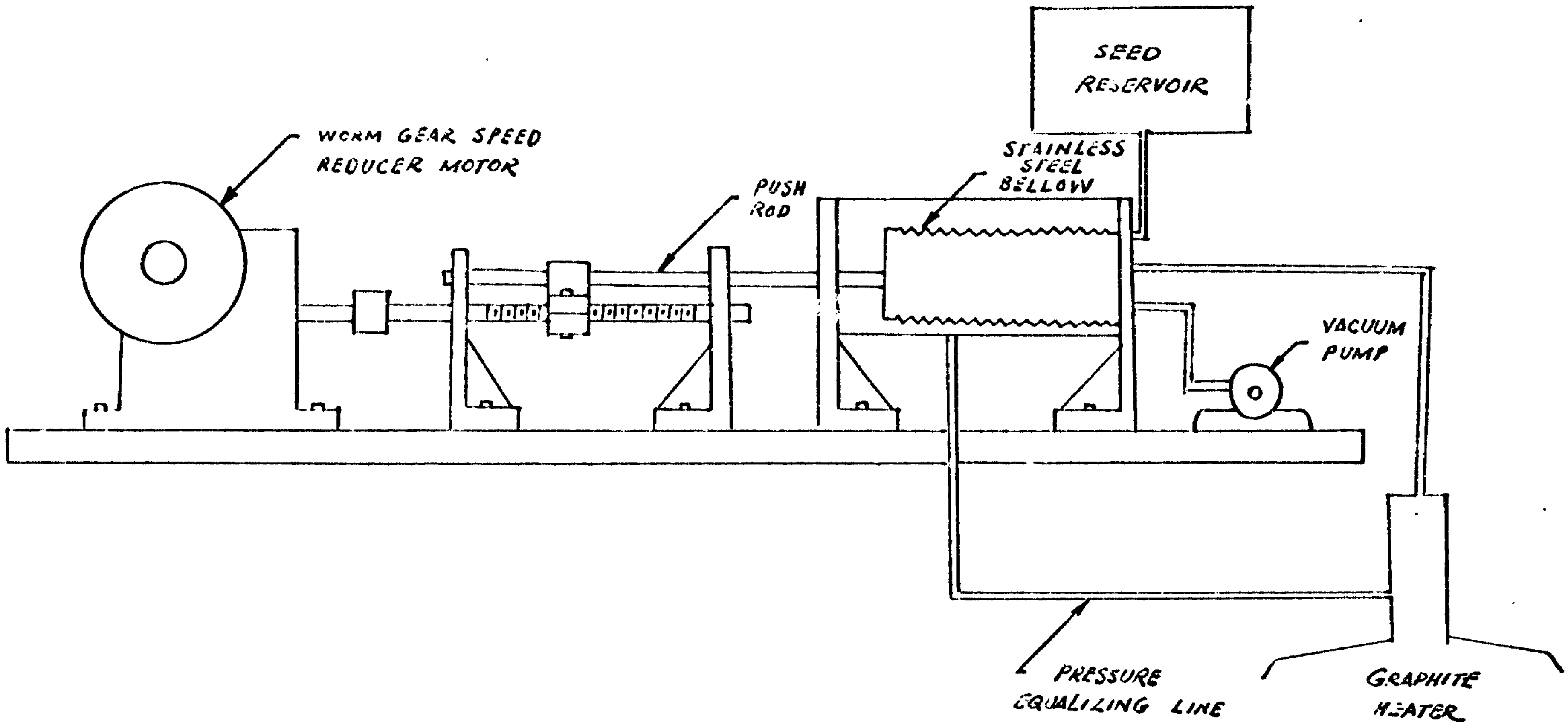


FIGURE 3

SKETCH DIAGRAM SHOWING SEED INJECTION SYSTEM

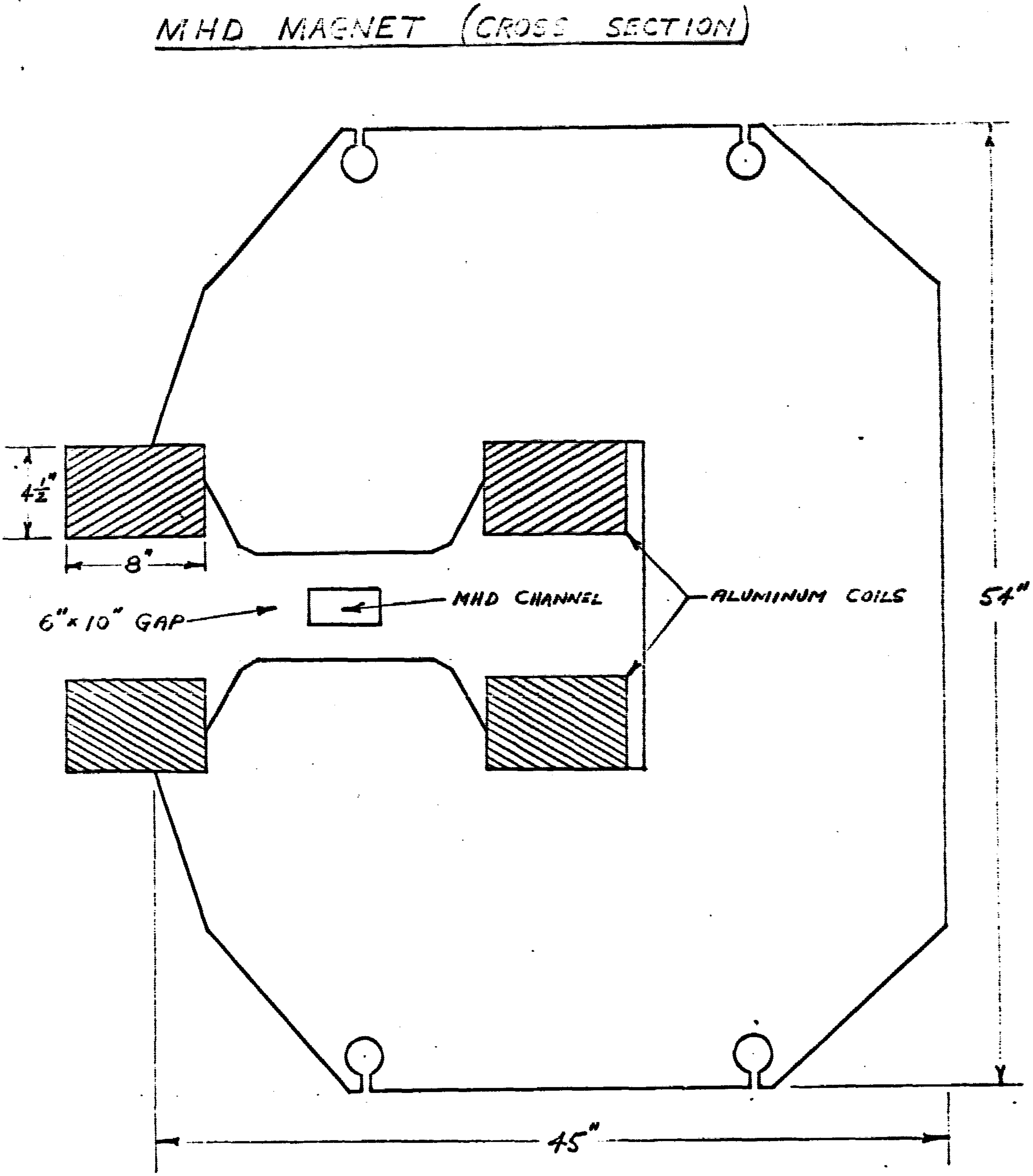
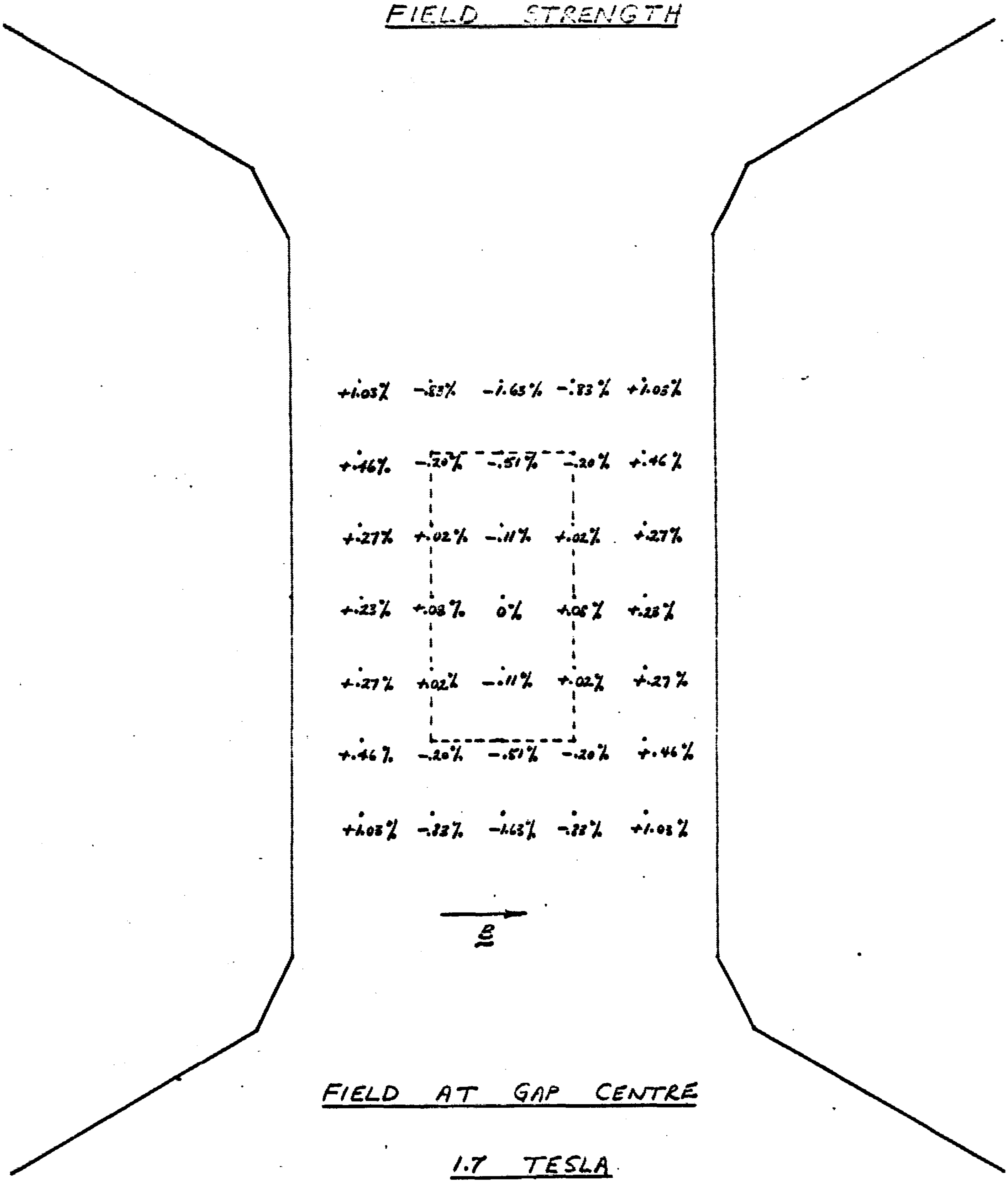

MHD MAGNET (CROSS SECTION)
$4\frac{1}{2}$"
8"
6" x 10" GAP
MHD CHANNEL
ALUMINUM COILS
54"
45"

FIGURE 4

GAP CROSS SECTION (6" × 10")

PREDICTED VARIATIONS IN

FIELD STRENGTH



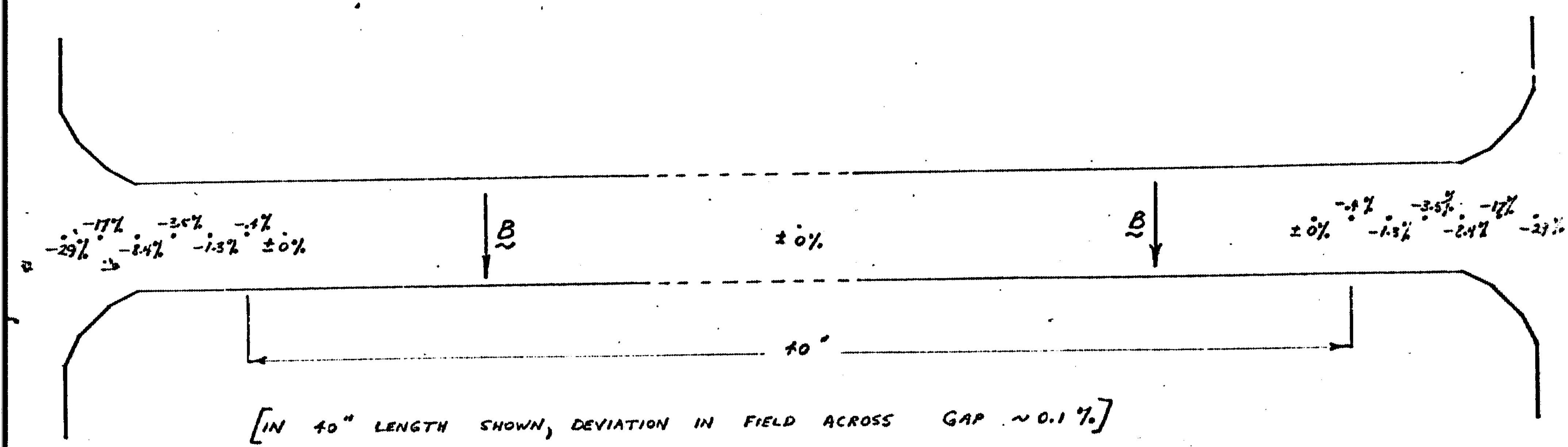
FIELD AT GAP CENTRE

1.7 TESLA

FIGURE 5

GAP CROSS SECTION (6" × 50")

PREDICTED VARIATIONS IN FIELD STRENGTH



FIELD ON AXIS IS 1.7 TESLA

(SCALE ½" = 1")

FIGURE 6