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Recent improvements in the performancce of the electrostatic separators

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EP & S DIVISION TECHNICAL NOTE

No. 21

R.A. Loper
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RECENT IMPROVEMENTS IN THE PERFORMANCE OF THE ELECTROSTATIC SEPARATORS

Introduction

For the past eighteen months the Beam Separator Group has been engaged in a testing and modification program in an effort to improve the performance of the existing electrostatic separators. The program to date has been directed towards improving the reliability of the separators and decreasing the conditioning time rather than an attempt to improve the voltage gradient. In the past the separators have been limited to two or three days of operation between conditioning periods for an all steel electrode system and to two weeks for glass cathode system. The time needed to condition has been from two to twenty-four hours depending on the type of separator and its history. At the same time we have been limited to a gap voltage of 500 kV across 10cm which is a compromise between a reasonable running time and a useable voltage gradient. A larger gradient could be expected across a smaller gap, but this is not always practical in some beam optical systems.

A further effort has been made towards the semi-automatic operation of dc separators which includes the conditioning mode as well as the operating mode. The objective in this program is the release of the separator operator from the around-the-clock operation.

The following sections are a summary of the work done over the past several months with an outline for a program in the future.

Pressure-Voltage Effect

The characteristics of an electrostatic separator under the influences of voltage, pressure, and magnetic field have been fully described by Sanford in the Accelerator Department Internal Report JRS-2. A curve from that report which is typical of all BNL separators is shown in Fig. 1 for convenience. The operating region for a separator is any point under the vacuum breakdown boundary and to the left of the gas discharge or critical pressure boundary. The effect of deconditioning is to lower the vacuum discharge boundary, and the effect of a crossed magnetic field is to bend the gas discharge boundary to the left. The symbol ΔV refers to the algebraic sum of the electrode voltages, hence $\Delta V = 0$ represents symmetrical voltages to ground on each electrode.

Gap Effect

Until recently none of the rectangular separators had ever been assembled using a 2-inch electrode spacing. The decision to change the rectangular separators in Beam #3 from a 4-inch to the 2-inch gap presented the opportunity for some testing. The curves of Fig. 2 are the results of these tests.

In a comparison of the pressure-voltage curves for this separator using both the 4-inch and the 2-inch gaps (Figs. 1 and 2) it can be seen that with no magnetic field applied, the voltage-pressure points are very nearly the same. This represents a doubling of the gradient of the electric field. Using a rule-of-thumb estimate that the gap voltage varies as the square root of the gap distance, we had expected a 40% increase in gradient. The fact that a higher gradient is obtained is an indication that the voltage limitations at the larger gap distances is an electrode to ground or feedthrough limitation, not a gap limitation.

One problem associated with the actual use of this separator with a higher gradient is that the magnetic field has to be increased proportionately. The effect of the higher magnetic field can be seen in Fig. 2. The gas discharge boundary is moved and bent considerably to the left, making gap voltages in excess of 400 kV impractical to use.

The Addition of Grounded Shields

As Sanford points out in his report it is the rather long region between the electrodes and the tank wall that causes the gas discharge boundary to shift with the presence of a magnetic field, With this in mind we installed a system of grounded shields in this region which in effect decreased the volume of the vacuum tank. A sketch of this arrangement is shown in Fig. 3. At the same time an additional improvement to the configuration of the electrodes was the installation of a set of covers on the backs of the electrodes. The grounded shields were installed such that the spacing from shield to electrode was equal to the gap between electrodes. The voltage gradient from the electrode to ground was therefore 1/2 the gradient between the electrodes with symmetrical voltages.

A voltage-pressure curve of the separator as described is shown in Fig. 4. It can be seen that the grounded shields have had an effect on the coupling between the magnetic field and the electrostatic field. A comparison between Fig. 1 and Fig. 4 shows that the gas discharge boundary is no longer shifted to the left by the presence of a magnetic field, but rather it is shifted slightly to the right. The result is a wider pressure operating region at the higher voltages. The shift to the right implies that the electrode to ground gradients should equal the gap gradient for least effect of the magnetic field.

The pressure operating region, labelled ΔP on the curve, is very important in the operation of a separator. It is the maximum pressure excursion that can be tolerated at a particular gap voltage before the separator will spark or draw excessive electrode currents. The width of the pressure region decreases with time, probably due to electrode contamination, as the separator is operated in the gas region (above 1×10^{-4} torr). The rate at which the ΔP diminishes is an indication of how long a separator will run between conditioning periods. When the ΔP becomes too small the operator must either reduce the gap voltage or terminate the operational period to condition. A plot of ΔP and time is shown in Fig. 5.

The curves show that the vacuum breakdown boundary changes at a linear rate. In fact tests have demonstrated that this change takes place whether or not a voltage is maintained continuously across the gap. It is quite evident that the use of grounded shields has increased the operating time of the separator. Although the separator is still capable of operation past the time shown in curve C of Fig. 5, a two week cycle of running and conditioning is all that is necessary to conform to the AGS running and maintenance schedule.

The cycling of the magnetic field to zero is required in all separators without grounded shields after a spark off. No cycling was necessary in the test separator which had grounded shields. A test was made with beam pipe stubs mounted on the ends of the test separator, and it was found that the requirement for cycling returned at pressures above 5×10^{-4} torr. Cycling, however, should not be a problem unless we decide to try to operate at some time in the future by riding through a spark or having to operate above 5×10^{-4} torr. The addition of the stubs did not appear to have any effect on the magnitude of the gap voltage that could be maintained, but the overall spark rate did appear to be slightly higher.

With the use of grounded shields an additional effect has been noted, the separator requires conditioning in the gas region also. After the usual conditioning in the 10^{-6} torr range where the separator draws a current across the gap, the voltage and pressure must be raised gradually to the operating region where the separator is allowed to spark. An initial spark rate of 15 to 20 per hour will decrease after several hours to a normal spark rate of 2 or 3 per 8 hour period.

Electrodes

We have seen in the past the evidence of sparking activity in the area around the shim of the steel electrodes. The shim, as illustrated in Fig. 6(a), was originally intended to give a uniform electric field over a wider portion of the plate. Inasmuch as less than 8 inches out of a total of 24 inches of plate width is used due to the beam pipe restrictions, the removal of the shim should improve operation without effecting adversely the useable field uniformity.

Procurement of new electrode surfaces for test of a design similar to Fig. 6(b) has been initiated. Back covers have been installed but not as yet tested.

Other Gases

The gas used in our separators has always been nitrogen for the reason that other gases, such as argon or helium, exhibited no significant improvement in operation. However, several gases were tried in the test separator with the grounded shields, and there were noticeable changes. For example, Fig. 7 is the familiar pressure-voltage curve, but with helium as the gas. A comparison of Fig. 7 and Fig. 4 shows a slightly flattened top and a wider ΔP for a particular voltage. The usefulness of a wide ΔP is also shown in Fig. 8 which is a comparison of helium and nitrogen under similar conditions. The use of helium as gas would definitely give longer operating periods. But with the current AGS maintenance cycle, conditioning time is available every two weeks so that the longer operating time may not be too important. One disadvantage of using helium is that the vacuum pumps must have the capability of being throttled in order to limit the gas flow rate to a reasonable level.

Some test runs were made using a 90% neon-10% helium mixture. The results were very nearly the same as with helium. Because of the cost of the neon-helium mixture and the similarity of the characteristics to helium, it does not appear feasible to consider the use of this mixture in any practical way.

Feedthroughs

One problem which previously required approximately 30 man hours of work every two weeks was the possibility of siphoning or migration of insulating oil out of the feedthroughs and into the high voltage cable. The preventative maintenance program required the draining of all feedthroughs followed by a measured filling. The difficulty was the fact that half of the feedthroughs are inverted where the filling is a vacuum process. In trying to find an answer to this problem two facts were known. One was that any previous attempt to leave the polyvinylchloride(PVC) sheath over the paper insulation as a seal caused a high voltage failure at ground where the cable entered the feedthrough. The other was that any sort of metal cap on the end of the cable would leave a metal scratch on the inside of the ceramic insulator when the cable was installed. A solution came about when it was realized that a metal end cap which carried the dc leakage path over the end of the PVC sheath and a 1/2" or so down the side prevented failure at ground. The addition of O-ring seals and a teflon abrasion ring resulted in a successful cable termination. These terminations have been added to all separators except the cylindrical type where the ceramic insulator also requires a modification. The bi-weekly oil changing routine has been reduced to these two separators.

The corona hardware on the feedthroughs has been redesigned to prevent carbon tracking along the vacuum side of the ceramic insulator. The longer corona rings together with a fluted insulator should improve the lifetime of the feedthrough. Testing of these designs has not as yet been completed.

Vacuum-Pressure

A servo controlled gas pressure regulating system manufactured by Granville-Phillips has been in use on our test separator for almost a year. This system allows the operator to set a pressure, and then this pressure is maintained constant by the servo system in conjunction with a motor operated needle valve. Pump speed variations and gas cylinder pressure changes are compensated for automatically and smoothly. Installation of these systems on all separators has been started.

Ionization gauges could not be used for vacuum readout in the past because of an interaction between the hot filament and the separator gap current in the high pressure operating region. Instead a cold cathode type vacuum gauge had to be used although this gauge had the disadvantages of poor readout resolution and a continual problem of contamination of the gauge head. However, to use the Granville-Phillips pressure regulation system, an ionization gauge is required as the pressure transducer for best control.

Two types of isolation were tried in the vacuum line between the ionization gauge and the vacuum tank. It was found that a magnetic ion trap or a grounded screen worked equally well. In a separator with the new grounded shields installed in the vacuum tank no further ionization gauge isolation is necessary. In regard to the filament life, we have found that the filaments last for six months or longer which is better than our experience with cold cathode gauges.

The requirement that for best operation separators be conditioned in the 10^{-6} torr range, but run in the 10^{-4} torr range, makes the selection of a vacuum pump difficult. One type of pump currently in use is an oil diffusion pump throttled by a valve at the higher pressures. Freon baffling is relied on quite heavily for this pump instead of the liquid nitrogen baffle with its inherent fill probelms. Another pump used more extensively on the separators because of its relative simplicity is the freon-baffled, roots-blower, mechanical pump. This system has several undesirable characteristics such as the inability to pump into the 10^{-6} torr range and the introduction of hydrocarbons into the separators.

It is hoped that the answer to the pump selection problem is the turbine molecular pump. This pump has the capability of evacuating a separator into the low 10^{-6} torr range and requires no baffling. No harmful effects are encountered when operating the turbine pump at the higher pressures. There are now three of these pumps installed with three more soon to follow. The only reservation at present is the lifetime of the turbine bearings and seals.

<u>High Voltage Power Supplies</u>

There is presently a total of 18 high voltage power supplies installed in the various beam lines and on the test separator. Of these, four are rated at 600 kV, 12 at 400 kV, and 2 at 300 kV. On all but the 600 kV units the voltage regulation systems were designed by the Separator Group and built by the AGS Shop. A current regulation system which is used when conditioning separators is being added to all supplies. The installation of a current regulation system on the 600 kV units is particularly difficult because of the carrier wave regulation scheme in use and built-in ground loop problems. In addition a new 600 kV voltage divider had to be designed to replace the original inadequate generating voltmeter and a subsequent voltage divider which did not stand up under the transients induced by the separators. The new dividers are presently undergoing test.

The output bushing on one type of 400 kV supply had to be redesigned to give better treatment to the high voltage cable at the ground point. The use of an adhesive-backed, copper foil tape for the first time also proved successful. This tape is used now on all high voltage terminations.

Projection into the Future

After many hours of separator testing and operation, it is apparent that our dc separators are limited to a gap voltage of 600 kV. Long term running at voltages of 300 kV per electrode or above eventually causes breakdown of the feedthroughs and the electrode supporting insulators. Trouble also occurs at the cable terminations and in surge resistor tanks. Voltage gradients above 600 kV on 10 cm, therefore, can only be obtained by a reduction in gap distance or wait upon the development of better components.

Some of the more successful modifications have been described such as grounded shields, electrode covers, corona hardware, and vacuum instrumentation. Now these changes should be incorporated into the remaining separators, and this has already begun. There are other ideas that should be tried such as better corona treatment of the glass cathode separators and fluted feedthrough insulators. But again, these ideas are only intended to improve the present mode of operation and increase reliability. These changes are not difficult to implement because they are modifications to an existing design. The development of new components necessary for increased voltages is a long term program. Many of the component designs currently in use would become obsolete, and it is expected that most of the components including the electrodes would be effected.

The manpower for a development program must come from the separator operating crew. The test separator has demonstrated that automated runs as long as three weeks can be made with occasional checks during the day shift. With proper interlocking against power failures, high spark rates, and vacuum failures together with a remote alarm system, there is reason to believe that modified separators could be run by the experimenter thereby releasing operators for an expanded modification program.

Acknowledgements

This report encompasses the work of many members of the Beam Separator Group. R. Hulliger has been helpful in the area of vacuum instrumentation and control. R. Talsma has been responsible for the improvements to the power supply regulation systems and has assisted in the separator operational and testing program. R. Monaghan and E. Heppner have provided the supervision necessary to carry on simultaneously the task of modification and the routine operation of the separators. The installation of the various modifications has been mainly the work of L. Potter, L. Zaloga, and O. Centabar.

In particular, acknowledgement is made of the assistance of John Walker who has been responsible for the mechanical design and procurement of the components used in the modification program.

Distr. Beam Separator Group
Dept. Administration

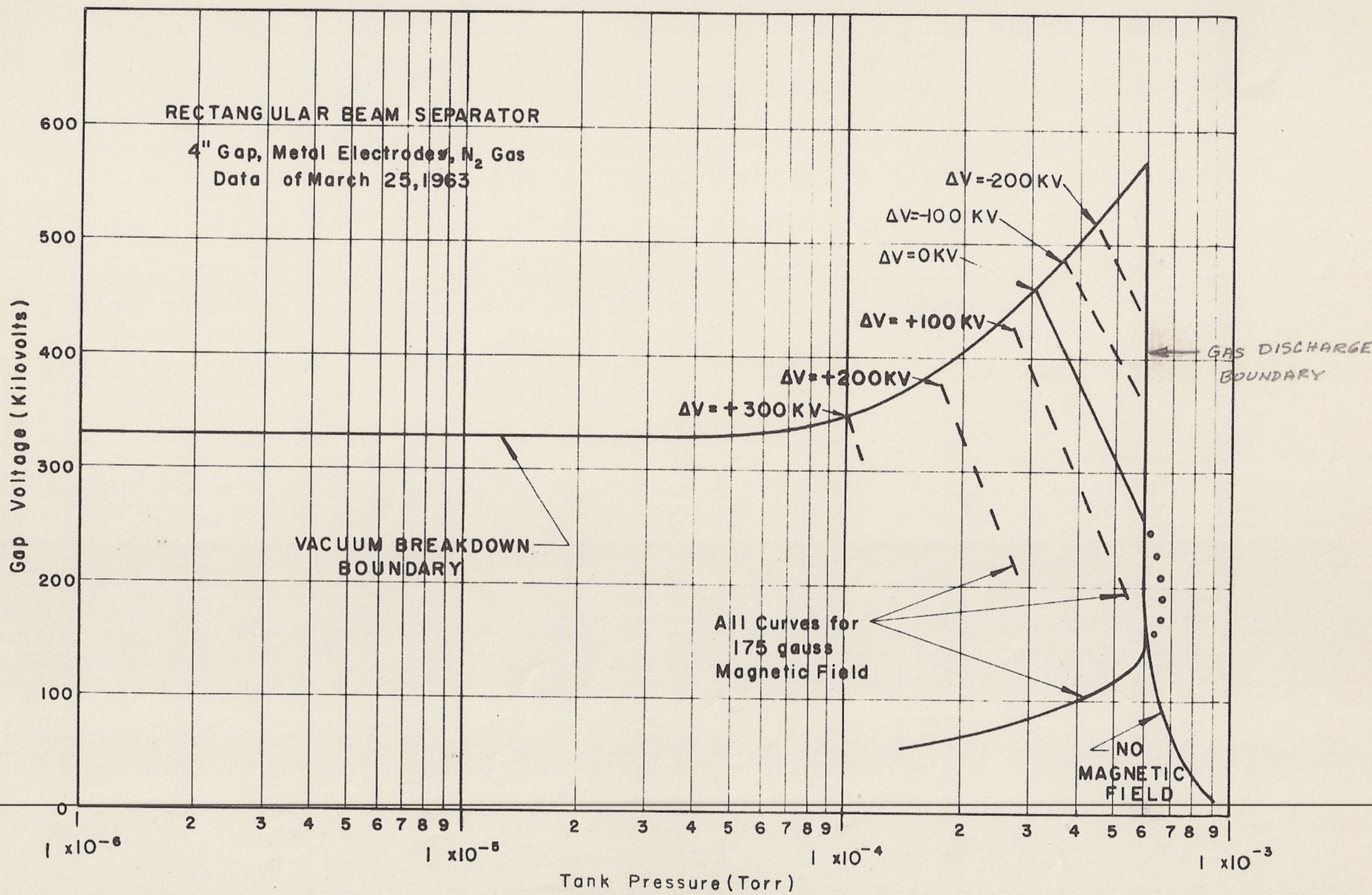

RECTANGULAR BEAM SEPARATOR
4" Gap, Metal Electrodes, N_2 Gas
Data of March 25, 1963
Gap Voltage (Kilovolts)
0
100
200
300
400
500
600
Tank Pressure (Torr)
1 x10^{-6}
1 x10^{-5}
1 x10^{-4}
1 x10^{-3}
2 3 4 5 6 7 8 9
ΔV=-200 KV
ΔV=-100 KV
ΔV=0 KV
ΔV= +100 KV
ΔV= +200 KV
ΔV= +300 KV
GAS DISCHARGE BOUNDARY
VACUUM BREAKDOWN BOUNDARY
All Curves for 175 gauss Magnetic Field
NO MAGNETIC FIELD

FIG. 1

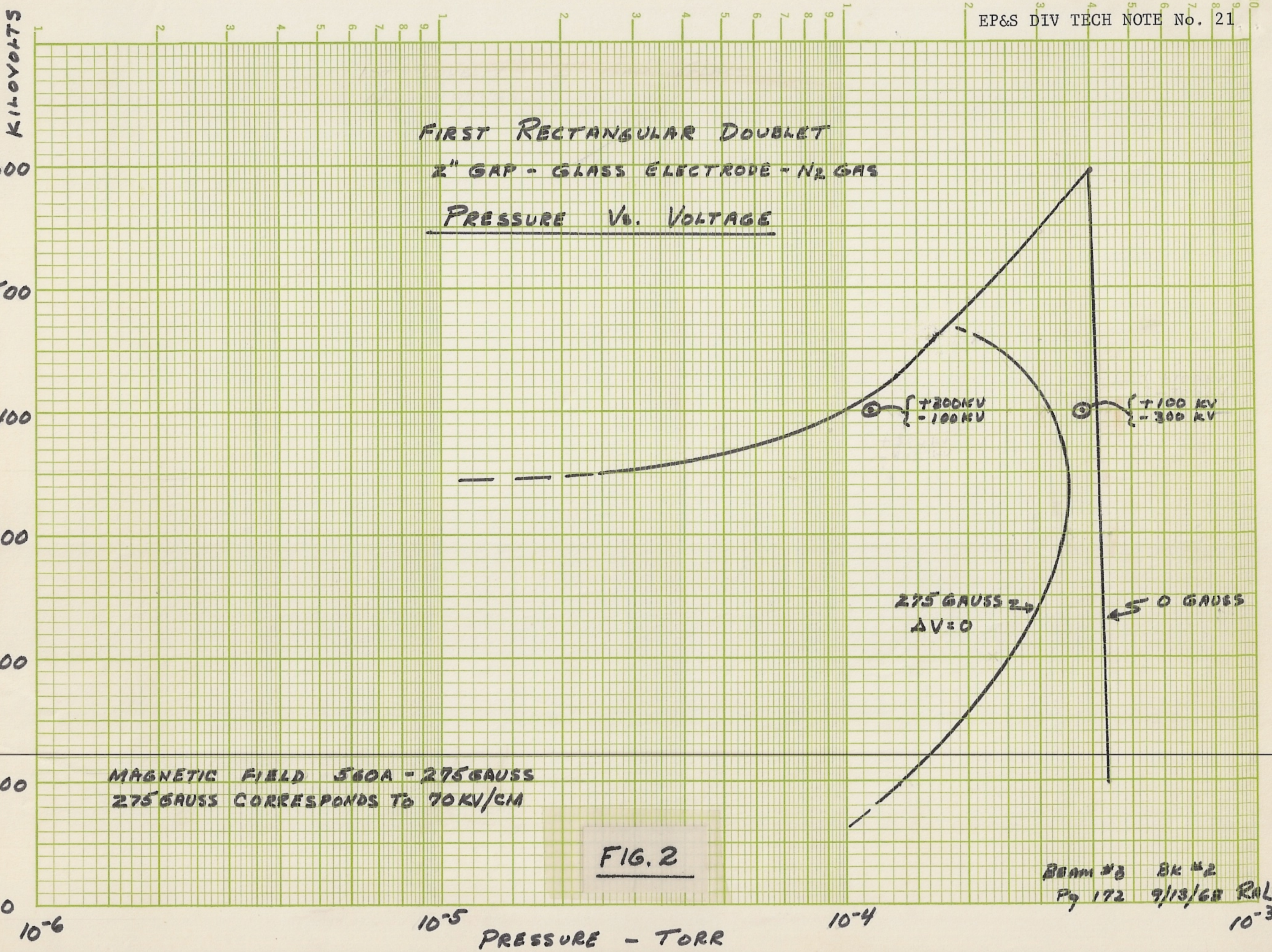
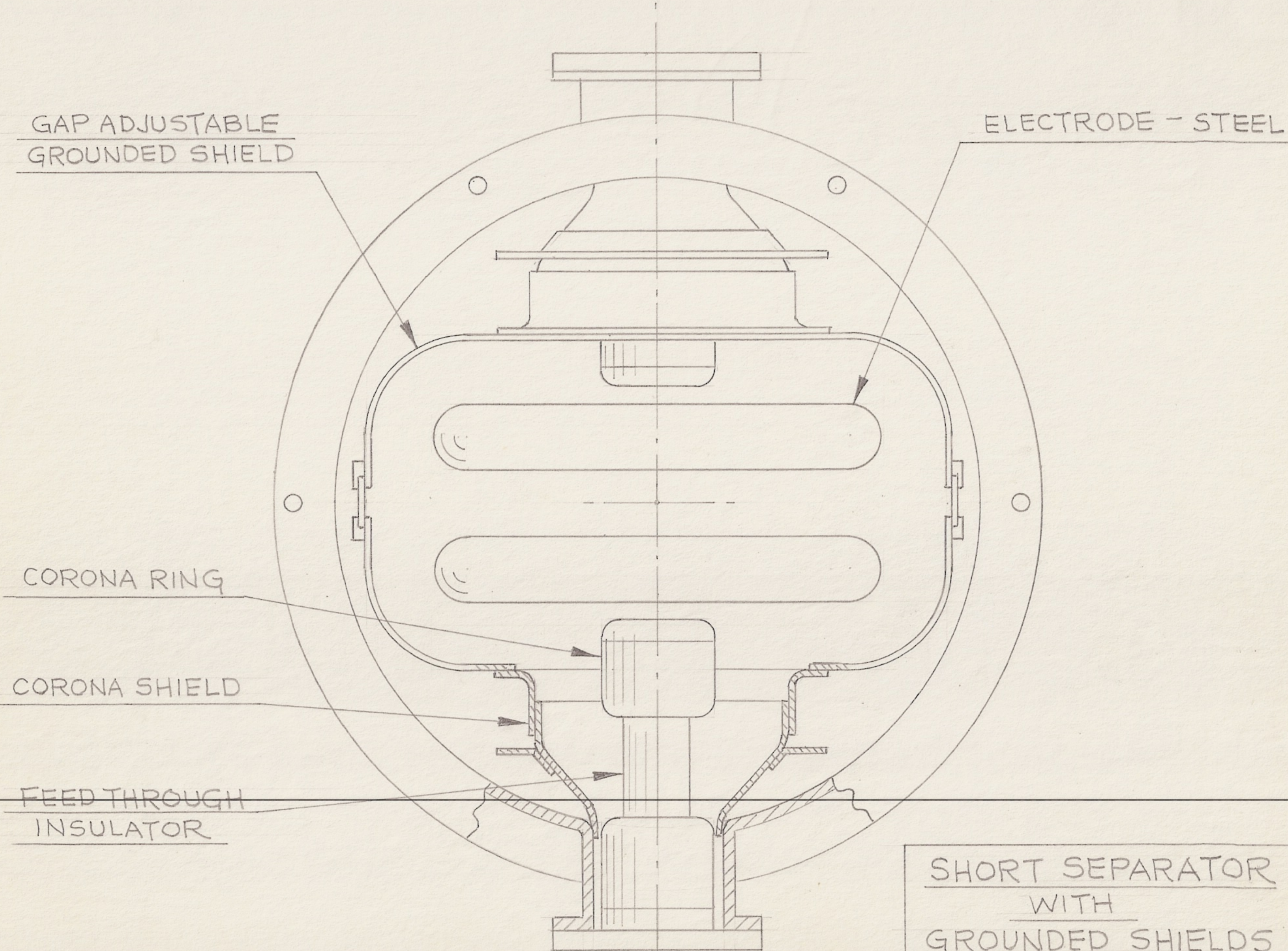

FIRST RECTANGULAR DOUBLET
2" GAP - GLASS ELECTRODE - N2 GAS
PRESSURE Vs. VOLTAGE
KILOVOLTS
600
500
400
300
200
100
0
+300KV
-100KV
+100 KV
-300 KV
275 GAUSS
ΔV=0
0 GAUSS
MAGNETIC FIELD 560A - 275GAUSS
275 GAUSS CORRESPONDS TO 70KV/CM
Beam #3 Bk #2
Pg 172 9/13/68 RAL
10-6
10-5
10-4
10-3
PRESSURE - TORR

FIG. 2



SHORT SEPARATOR
WITH
GROUNDED SHIELDS
(END VIEW)

FIG. 3

10/68

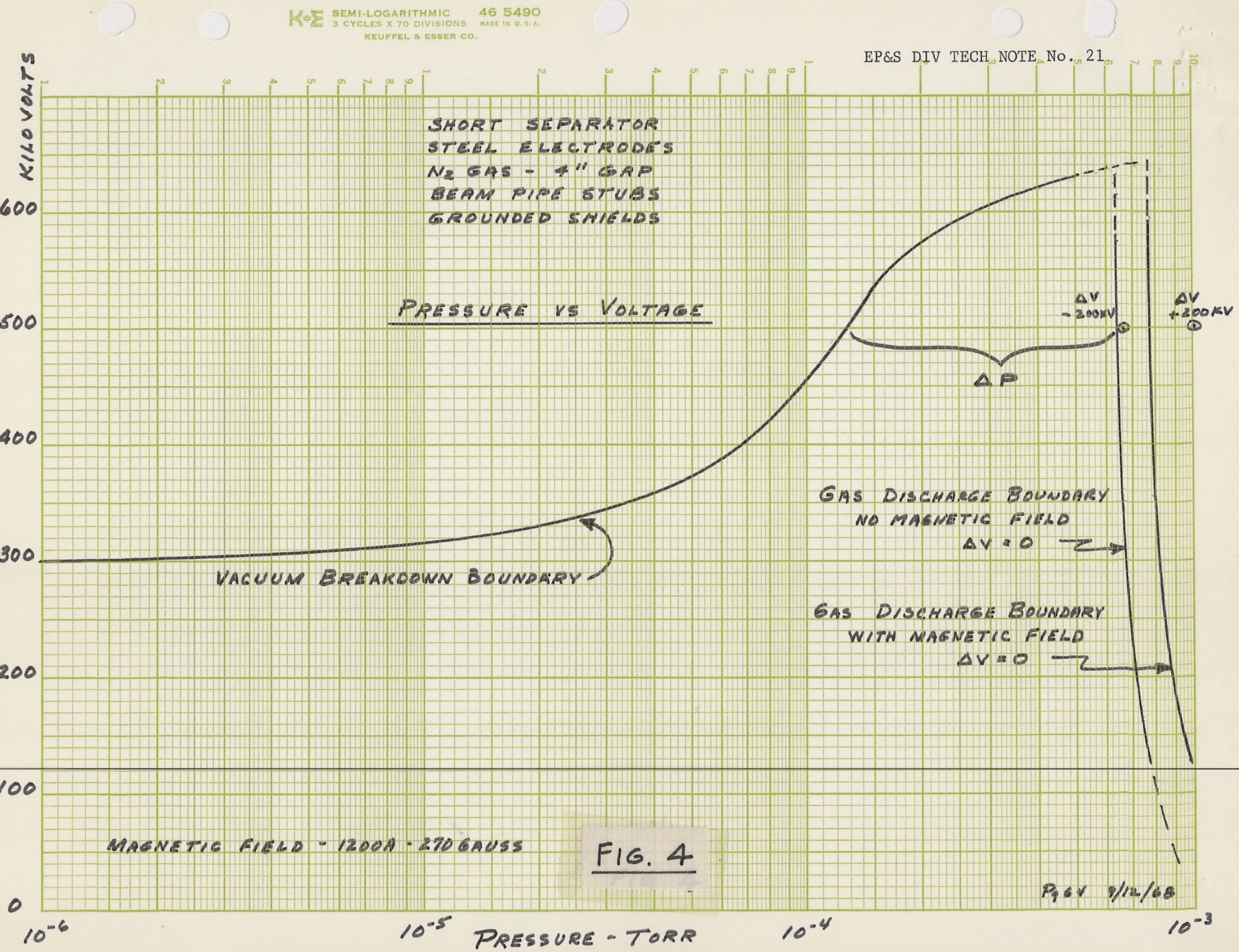

K+E SEMI-LOGARITHMIC 46 5490
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.
SHORT SEPARATOR
STEEL ELECTRODES
N2 GAS - 4" GRP
BEAM PIPE STUBS
GROUNDED SHIELDS
PRESSURE VS VOLTAGE
ΔV -200KV
ΔV +200KV
ΔP
GAS DISCHARGE BOUNDARY
NO MAGNETIC FIELD
ΔV = 0
VACUUM BREAKDOWN BOUNDARY
GAS DISCHARGE BOUNDARY
WITH MAGNETIC FIELD
ΔV = 0
MAGNETIC FIELD - 1200A - 270 GAUSS
KILOVOLTS
600
500
400
300
200
100
0
10-6
10-5
10-4
10-3
PRESSURE - TORR
P9GV 9/12/68

FIG. 4

K+E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

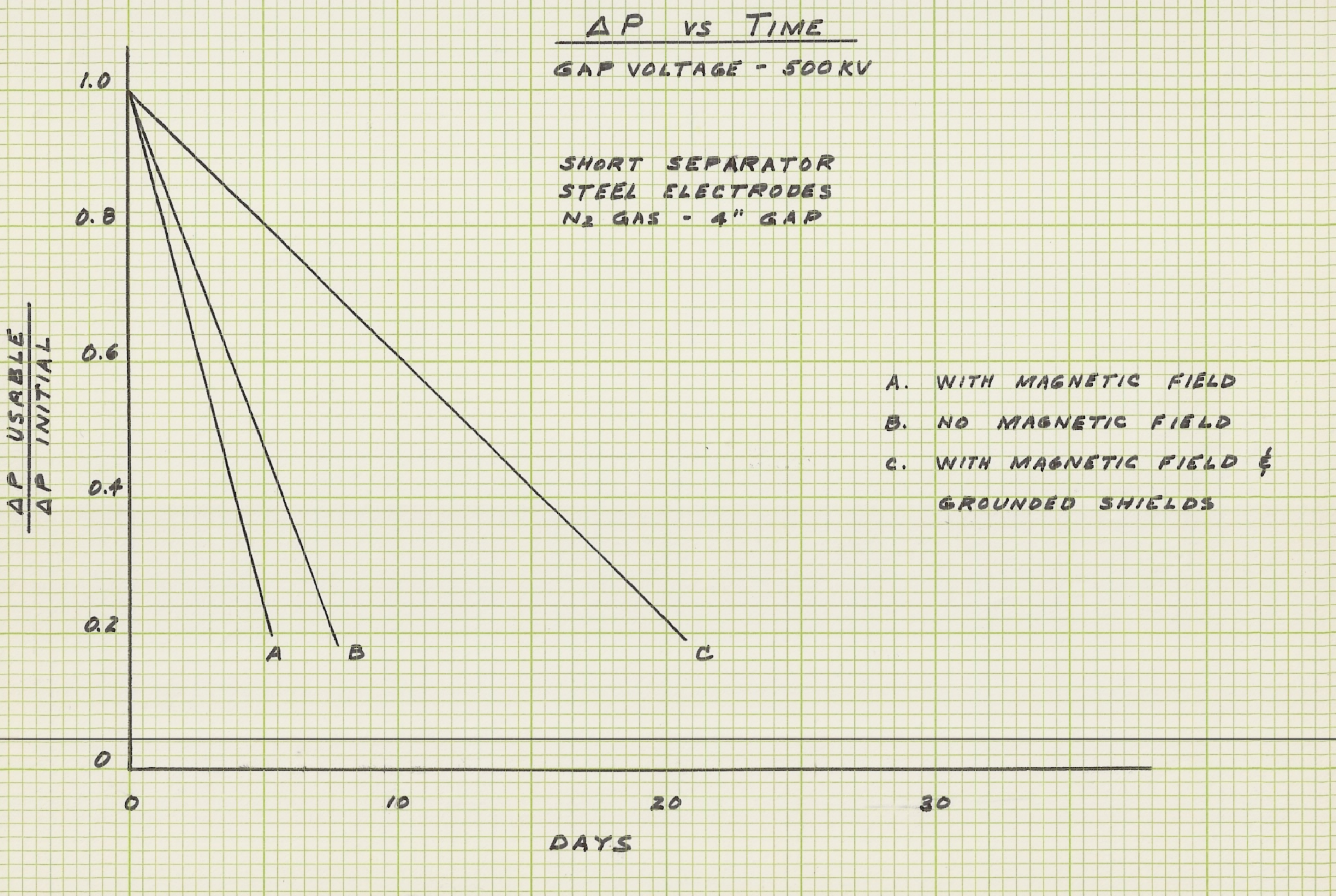


FIG. 5

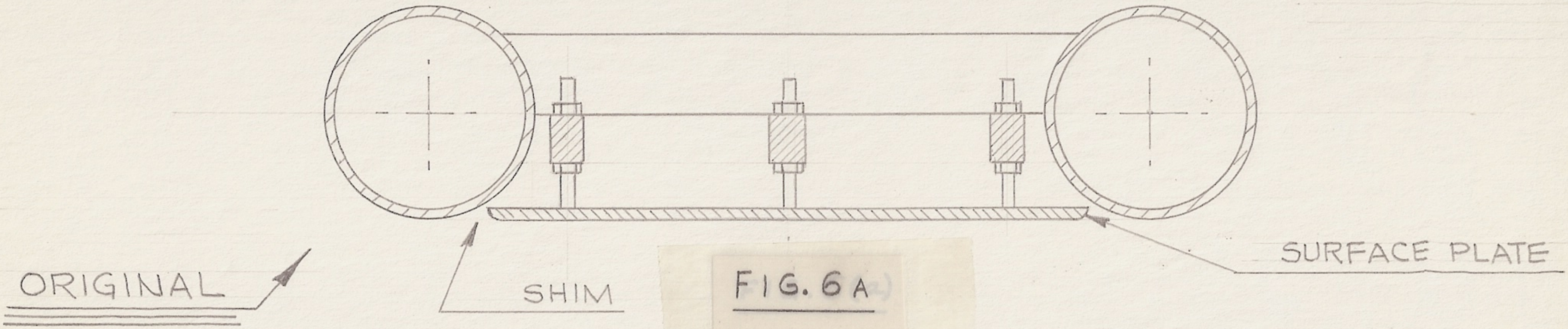


FIG. 6A

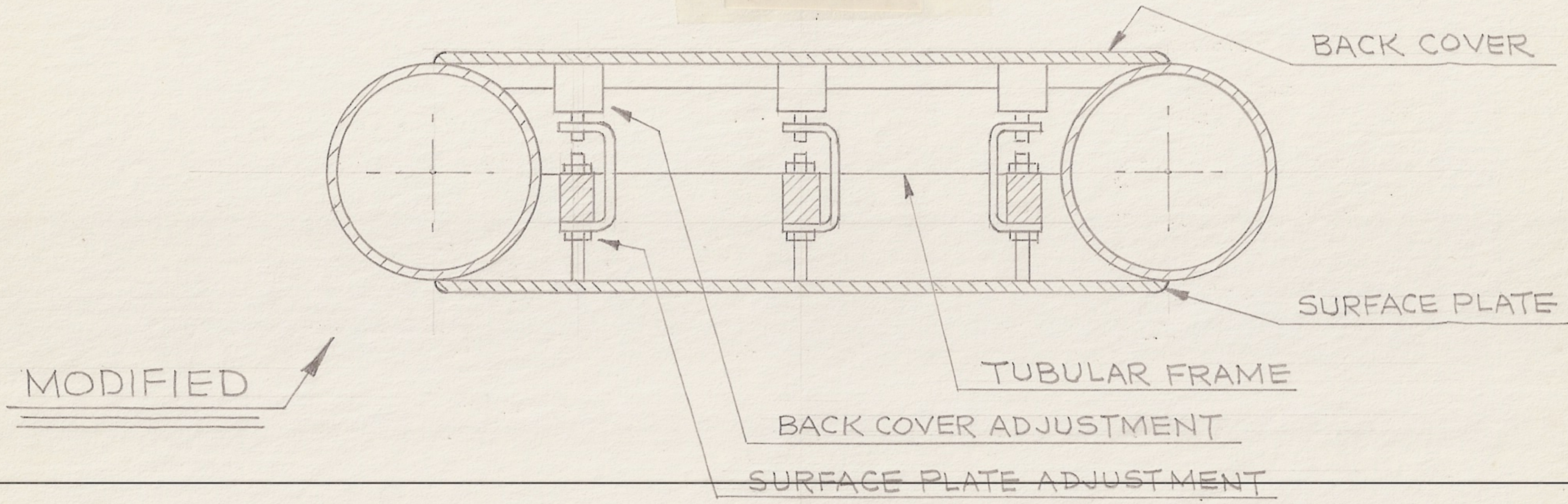


FIG. 6B

SHORT SEPARATOR
ELECTRODE MODIFICATION
(SECTIONAL VIEW)

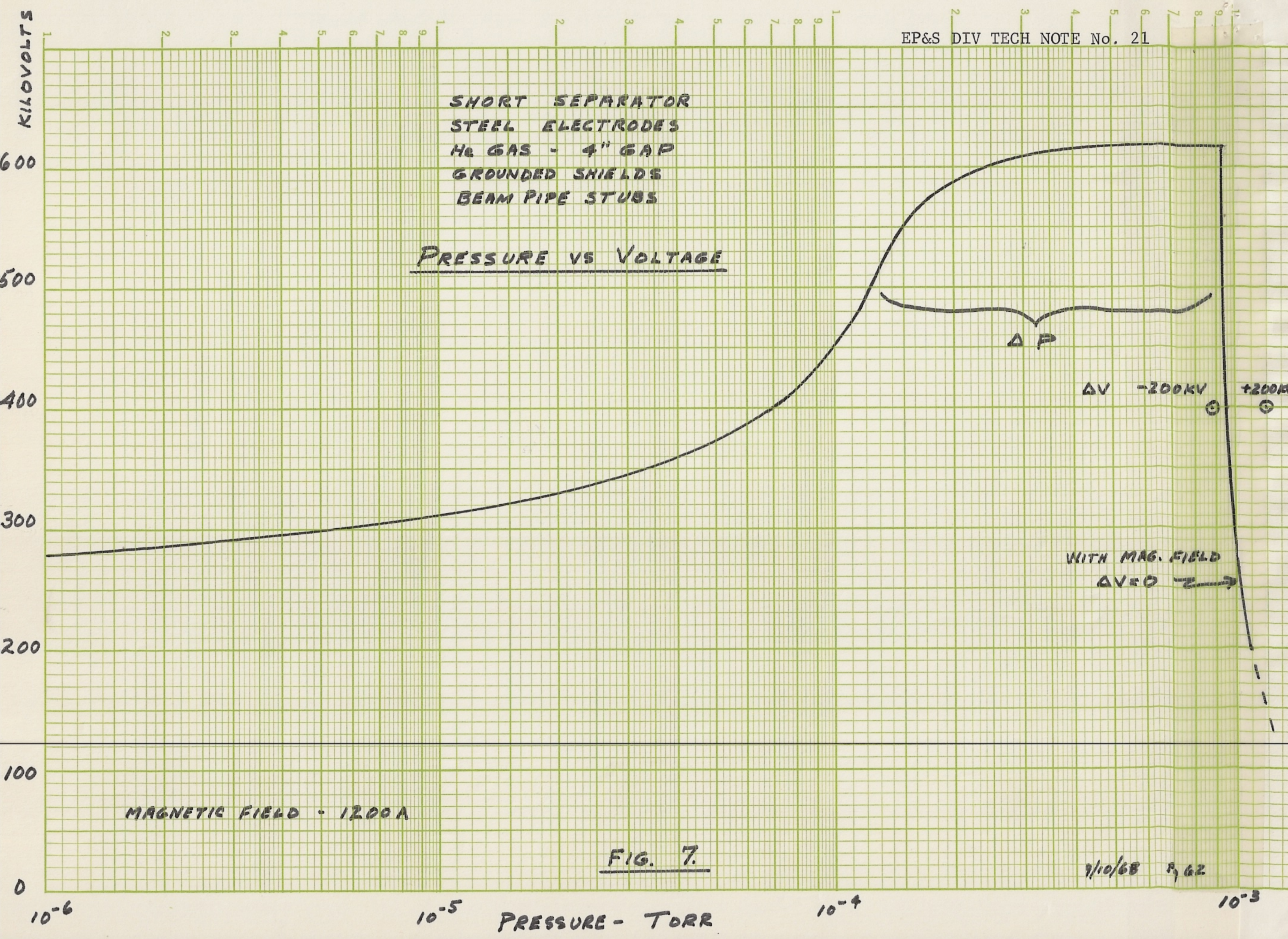

KILOVOLTS
600
500
400
300
200
100
0
SHORT SEPARATOR
STEEL ELECTRODES
He GAS - 4" GAP
GROUNDED SHIELDS
BEAM PIPE STUBS
PRESSURE VS VOLTAGE
ΔP
ΔV -200KV +200KV
WITH MAG. FIELD
ΔV=0
MAGNETIC FIELD - 1200A
9/10/68 Fj 62
10-6
10-5
10-4
10-3
PRESSURE - TORR

FIG. 7.