

FINAL REPORT

IMPROVEMENT OF MAGNETIC HEADS
THROUGH THE USE OF NEW AND
REFINED CORE MATERIALS

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FINAL REPORT

1. Introduction

This report reviews the development of the process for making ferromagnetic films with high permeability and the development of the technology for fabricating a head using these films. During the development some difficult assembly problems were revealed which had not been anticipated when the six-month extension was negotiated.

Despite the difficulties, the following has been achieved:

1. An interim head (which did not use a deposition process but fulfilled the requirement of having no organic material present in the face) was successfully built, tested, and delivered for evaluation in mid-April.
2. A process for sputtering high permeability films (0.0001" thick) has been developed.
3. Two heads, with deposited pole tips, have been tested and delivered. One (A) had a 0.0001" gap. The output vs frequency curve is shown in fig. 6. Unfortunately, the gap opened up while the head was being mounted. The other (B) had a 0.0003" gap and the output is shown in fig. 7. Both heads were bonded with epoxy but served to test the geometry of the head design, and have been delivered for further evaluation.

2. Previous Work

Prior to the interim report, a considerable effort was made to deposit high permeability Alfesil films in the D. C. sputtering equipment. At the time of the interim report, it was judged that high permeability Alfesil could not be made by D. C. sputtering and so two alternative approaches were pursued. One was the sputtering of Alfesil in an R. F. system and the other was the deposition of Permalloy in the D. C. system.

3. The Interim Head

A single track head was designed and fabricated by conventional techniques, and delivered to NASA in April 1971 to facilitate their in-house testing program. The head was constructed in such a manner that the pole tips, gap, and bracket were bonded by brazing thus presenting an all metal surface in contact with the tape. The general pole tip configuration was similar to the contract requirement with the exception of the pole tip dimension. The pole tip length was 0.001", achieved by conventional machining techniques.

This head was delivered as an interim product of the contract while the efforts of depositing the smaller pole tip (.0001") continued.

4. Summary of Work Done to Develop High Permeability Films

4.1 The Problem: The preparation of an all-deposited head was considered as comprising two distinct developments. The first was to develop the technique for depositing Ferromagnetic films with an initial permeability of 1,000 or more. The second was the development of a process for fabricating a head using deposited films for the pole tips.

The first problem will now be considered.

The program was initially started with the intention of using Alfesil films (85:9:6, Fe Si Al) because this material is physically hard as well as having a high permeability.

High permeability is a difficult property to achieve even in bulk material. In fact, it is probably more sensitive to structure and strain than any other material property.

In both the Permalloy system (about 80:20: Ni Fe) and the Alfesil system, extremely high permeability is achieved by combining near-zero anisotropy with near-zero magnetostriction. Complete immunity to anisotropy and magnetostriction cannot be achieved because both quantities have two components (in cubic material) which don't vanish simultaneously in any composition. Because of this, the highest permeabilities are only obtained by annealing the material. The anneal has some or all of the following effects:

- a. Recrystallization
- b. Elimination of strains
- c. Reduction of imperfections
- d. Development of a magnetic superlattice

When it is realized that deposited films have a defect density of about 100 times that of cold-worked bulk material, the difficulty of trying to make high permeability films can be appreciated.

The choice of sputtering in preference to vacuum evaporation was originally made because of the superior composition control for such alloys as Alfesil. In fact, Alfesil could only be evaporated by using a flash evaporation source. Sputtering, however, has the disadvantage of "contaminating" the film with inert gas molecules, some of which are inevitably built into the structure. Fig. 1 emphasizes this problem. Here the vertical axis gives the rate of deposition and the horizontal axis is the pressure (both on a log scale).

The line marked "R = 1" is the locus of the conditions for an equal number of deposited atoms and gas atoms reaching the substrate. For example, at 10^{-7} Torr there are 3.8×10^{13} atoms hitting each square centimeter of surface per second. A deposition rate of 0.3 Å per second of Ni would give the same number.

This is Point X in the figure.

From the point of view of contamination, it is desirable to work in a region where "R" is about 10 or more. With an evaporation system, this is easily achieved by having a system which can pump down to 10^{-7} Torr and depositing at a rate of about 3 Å per second. However, with sputtering, the backfill of inert gas to about 10^{-2} Torr puts the deposition conditions into an operating region where "R" is about 10^{-3} . As a result of this large ratio of inert atoms to deposited atoms hitting the substrate, it is inevitable that a fraction of the gas is built into the structure. This is known to have a large effect on the resistivity of gold and tantalum films. It is not surprising, therefore, to find that the permeabilities of sputtered films are much lower than those of evaporated films.

Bias sputtering, however, can reduce the contamination built into films and has been shown to reduce the Argon content of nickel films. Bias sputtering has also been used to make thin gold films with resistivities equal to that of the bulk material.

- 4.2 Program To Develop High Permeability Films: Because the application of sputtering to film deposition is comparatively new and still developing, the above-mentioned problems, concerned with obtaining high permeability, were not fully appreciated at the start of the project. At the beginning of the extension, it was generally recognized in the sputtering industry that alfesil should be deposited by R. F. sputtering because of the highly oxidizable nature of the Al content. This was done as a service and several films of Alfesil were deposited onto substrates held at 230°C.

The substrates used were glass, Al_2O_3 and silicon (semiconductor wafer) and a range of three thicknesses were deposited: 0.14 μ , 1.4 μ , and 4 μ .

At this time only the H_c was measured as the measurements were made in the open flux loop plotter at UCSB. Because initial permeability and coercivity are affected by the same structural properties, the two are closely related and it can be assumed that material exhibiting a low coercivity will have a high initial permeability.

The coercivities of the above-mentioned films showed some substrate dependence (especially the thinner films), but the 4 μ films all had coercivities in the range of 10 Oersteds.

The effect of annealing in vacuum was tried and it was found that the coercivity could be reduced to 3 Oersteds by a prolonged heating to, and cooling from, 600°C (17 hours total). This reduction was poor compared to an annealing experiment tried on a 1 mil-thick sample taken from the target material and it was concluded that the difference was due to the bad match in the coefficient of expansion between the film and the substrate.

To confirm this, another set of 4μ -thick films were deposited on several substrates. The substrates and the values of coercivity are listed below:

	<u>Substrate</u>	<u>H_C</u>
1.	Palladium	8
2.	Palladium coated with 200 Å quartz	13
3.	Al ₂ O ₃	12
4.	Al ₂ O ₃ coated with 200 Å quartz	10
5.	Glass coated with 200 Å quartz	16
6.	Oxidized silicon	13

Palladium was chosen because of its close match to the thermal coefficient of expansion of Alfezil (12×10^{-6} deg C⁻¹). The deposited coating of quartz was used to prevent the possible diffusion of the iron into the palladium substrate. The quartz on the alumina and glass substrates was used as a check on the effect of the quartz coating on the surface.

The results show a small spread in coercivities with a slight improvement due to the palladium.

After annealing at 800°C, the film deposited on the quartz-coated palladium showed a dramatic improvement in H_C as shown in fig. 2. At full drive the H_C was about 1 Oersted and reduced to less than 0.5 Oersteds when the film was driven to about one-third of saturation. This compared well with the 1 mil material taken from the target. As expected, the film on palladium alone diffused into the substrate and the films on the other substrates behaved similarly to the results reported above.

From these results it was concluded that high permeability films could be made using Alfezil provided the substrate matched the expansion coefficient of the film (an inconveniently large coefficient for ceramics) and that a vacuum anneal could be made. Both these considerations would make device applications difficult.

Permalloy: At the same time, work was started using Permalloy in the D. C. sputtering system at AMC. Because there was some doubt about the ability of the system to deposit good quality magnetic films, it was decided to try Permalloy as there is a substantial literature on the properties of Permalloy films made by vacuum deposition.

The initial depositions, from Hy-Mu 800 sheet and Hy-Mu 80 1/4" stock, were disappointing as the coercivities were around 20 Oersteds and the material was not amenable to vacuum annealing. To ensure a fair comparison with previous work, a target of pure 80:20 Ni Fe was purchased. Again, the results were disappointing. These films had an H_C of about 20 Oersteds and a low initial permeability (which

was being measured by now). At this point, it was questionable as to whether this was a limitation of the particular equipment being used or a general limitation of sputtering. To check this it was decided to further "clean up" the system. Altogether, the following modifications were carried out:

1. Eliminate all non-metallic parts (except the Pyrex bell jar);
2. Screen all except the front surface of the target with a stainless steel grounded shield;
3. Provide a substrate heater (500 watt quartz iodide lamp in stainless steel reflector);
4. Replace Argon regulation valve with one containing no rubber derivatives;
5. Replace water-cooled baffle (which was found to have a leak) with nitrogen-cooled baffle;
6. Insert a second gate valve below the baffle to throttle the system while sputtering so that the nitrogen trap could act as a pump during the sputtering;
7. Change the pump oil for Corning 705;
8. Completely clean the system, including replacement of most of the "O" rings.

After completing these improvements, the system performance was noticeably better. For example, pressures about 5×10^{-7} are reached after an overnight pumpdown whereas it had been difficult to get on to the 10^{-6} scale previously. It was also found possible to deposit films having an initial permeability of over 2,000 provided the substrate temperature was held at 325°C during the deposition.

The substrate surface temperature is monitored with an infrared pyrometer.

The high permeabilities obtained under these conditions are independent of the coefficient of expansion of the substrate material and are more consistent with the results previously reported for evaporated films.

It is felt that there is considerable room for improvement in permeability of Permalloy films and that it should also be possible to make Alfesil films with similar properties, but it was decided that the development had proceeded far enough to make a deposited head feasible so the effort was switched to depositing films on the ceramic substrates for the head.

5. The Deposited Head

The original design suggested is shown in Fig. 3a. As the calculation

of the magnetic reluctance given in the appendix shows, this is a very bad magnetic circuit. A new design, shown in fig. 3b and 4, was then conceived which overcame this problem and should be able to make use of films with permeabilities as low as 1000.

The original intention was to use a 300μ " shim (hyvar or mica) in the front and bond the two halves together with a low-temperature glass. The glass bonding was considered doubtful for the following reasons:

1. To get the low-temperature glasses to flow satisfactorily, a temperature of about 600°C was required and this was shown to cause serious oxidation of the Permalloy film if done in air.
2. The glass-to-metal seal, which needed to be formed, must chemically react with the Permalloy and it is not known how much would be destroyed.
3. Tests of "melting" glass on Permalloy-coated ceramics suggested that the glass would not wet the Permalloy properly.

Because of these objections, the alternative of bonding with solder was devised. To do this, the head halves were deposited with the following coatings:

1. About 500 \AA chromium - to form a good bond to the ceramic and ferrite.
2. 100μ " of Permalloy in the areas marked A in fig. 5.
3. 40μ " of chromium on the areas A.
4. 10μ " of copper all over the front face.

In this way the chromium and copper automatically insure that a 100μ " gap exists in the area of the Permalloy pole tips.

The following attempts were made to put a head together:

1. A head was glass-bonded in air at 580°C . The hyvar shim became displaced and the glass didn't flow sufficiently to bond.
2. A head was glass-bonded in nitrogen at 600°C . There was a slight mis-registration between the two halves, but the head was ground and wound with wire. No output was obtained and it appeared that there was no gap between the pole tips.
3. A head was soldered at 200°C in air. Oxidation of the copper made the bond fail.
4. A head was soldered in nitrogen. Because of insufficient pressure, the gap increased to 2 or 3 mils.
5. A head was soldered in nitrogen with more pressure. An insufficient bond resulted and it appeared that the copper alloyed with the solder.
6. A head was bonded with epoxy to test the geometry. This head was ground and tested. The results are shown in fig. 6. Regrettably, the head was overheated in an attempt

to mount it in a bracket and the gap opened up.

7. A head was soldered with low melting point silver solder (425°F). This approach resulted in a good bond, however new tooling would be required to assure good registration and alignment during bonding. This head was misaligned and the ceramic face broke during grinding because some of the solder had flowed into the tiebar gap.
8. Another head was bonded with epoxy. This head was tested and delivered. The gap on this head is about 300μ ". The test results are shown in fig. 7.

Conclusions

The details, involved in the fabrication of a magnetic head with deposited pole tips of .0001 inch, proved to be more difficult than originally anticipated at the beginning of this R & D effort. However, several techniques evolved during the program that prove the feasibility of production of such a head configuration.

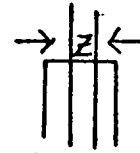
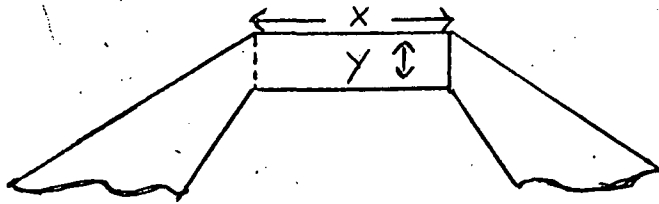
The development of the techniques, required to produce the ultra small pole tips with a suitable high permeability material, consumed by far the greater effort during the program. Even after suitable films were produced, assembly problems with such thin films and a complex head configuration proved to be very tedious. In all, eight complete head assemblies were attempted. The major assembly problems were the perfection of techniques to align the two half shells during the bonding process and the control of the bonding process.

Material selection was also a major consideration. Differential thermal expansion of the various materials involved created some engineering problems.

All of these problems have been solved to the degree that it can be clearly stated that deposited magnetic heads of the configuration specified by the contract, are feasible. In the event that the NASA in-house development and testing programs reveal distinct advantages of the small tip configuration, they can be produced for practical applications.

APPENDIX

1. Thin Film Head Geometry



Reluctance of Gap: $R_g = \frac{L_1}{A_1} = \frac{Z}{XY}$

Reluctance of Pole: $R_p = \frac{L_2}{\mu A_2} = YZ\mu$

Ratio $\frac{R_p}{R_g} = \left(\frac{X}{Z}\right)^2 \frac{1}{\mu}$ (This is independent of Y)

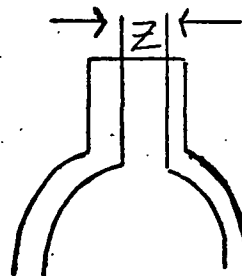
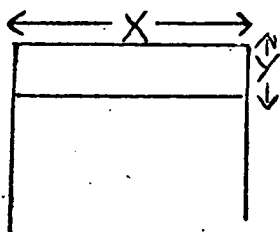
For $R_p = R_g, \mu = \left(\frac{X}{Z}\right)^2$

Put $X = 50 \text{ mils} \ \& \ Z = 0.1 \text{ mil.}$

Then $\mu = (500)^2 = 25 \times 10^4$

This geometry obviously demands a very high permeability if it has any chance of being efficient.

2.



Reluctance of Gap as before, $= R_{g1} = \frac{Z}{XY}$

Reluctance of Pole $R_p = \frac{Y}{XZ\mu}$

Now $\frac{R_p}{R_g} = \left(\frac{Y}{Z}\right)^2 \frac{1}{\mu}$ (independent of X)

Put $Z = 0.1$ mil, then the required value of μ (for $R_p^1 = R_g$) for different values of Y are given in the following table.

Y	$\frac{Y^2}{Z^2}$	$\left[= \mu \text{ (fw } R_p^1 = R_g) \right]$
1	100	
2	400	
3	900	
4	1600	
5	2500	

This shows that if the dimension "Y" can be kept down to about 1 mil, the geometry is not critically dependent on having high μ material.

Another requirement is that the rest of the magnetic circuit shall have a low reluctance.

If the effective core dimension can be thickened to 10 mil within 10 mils of the pole tip, and the total path length is taken as $1/4$ ", the core reluctance will be:

$$R_c = 2 \left[\frac{10 \times 10^{-3}}{5 \times 10^{-3} \times 50 \times 10^{-3} \mu} \right] + \left[\frac{250 \times 10^{-3}}{10 \times 10^{-3} \times 50 \times 10^{-3} \mu} \right]$$

$$= \frac{80}{\mu} + \frac{500}{\mu}$$

$$\text{The total magnetic path reluctance} = R_c + 2 R_p^1 \left(\frac{80}{\mu} + \frac{80}{\mu} + \frac{500}{\mu} \right)$$

$$= \frac{1380}{\mu}$$

$$\text{The gap reluctance is } R_g = \frac{10^9}{10^{-3} \times 50 \times 10^{-3}} = 2$$

This shows that the magnetic circuit reluctance is reduced below that of the gap by a permeability $< 1,000$.

This, therefore, is a very promising geometry.

Deposition Rate
(Ni)

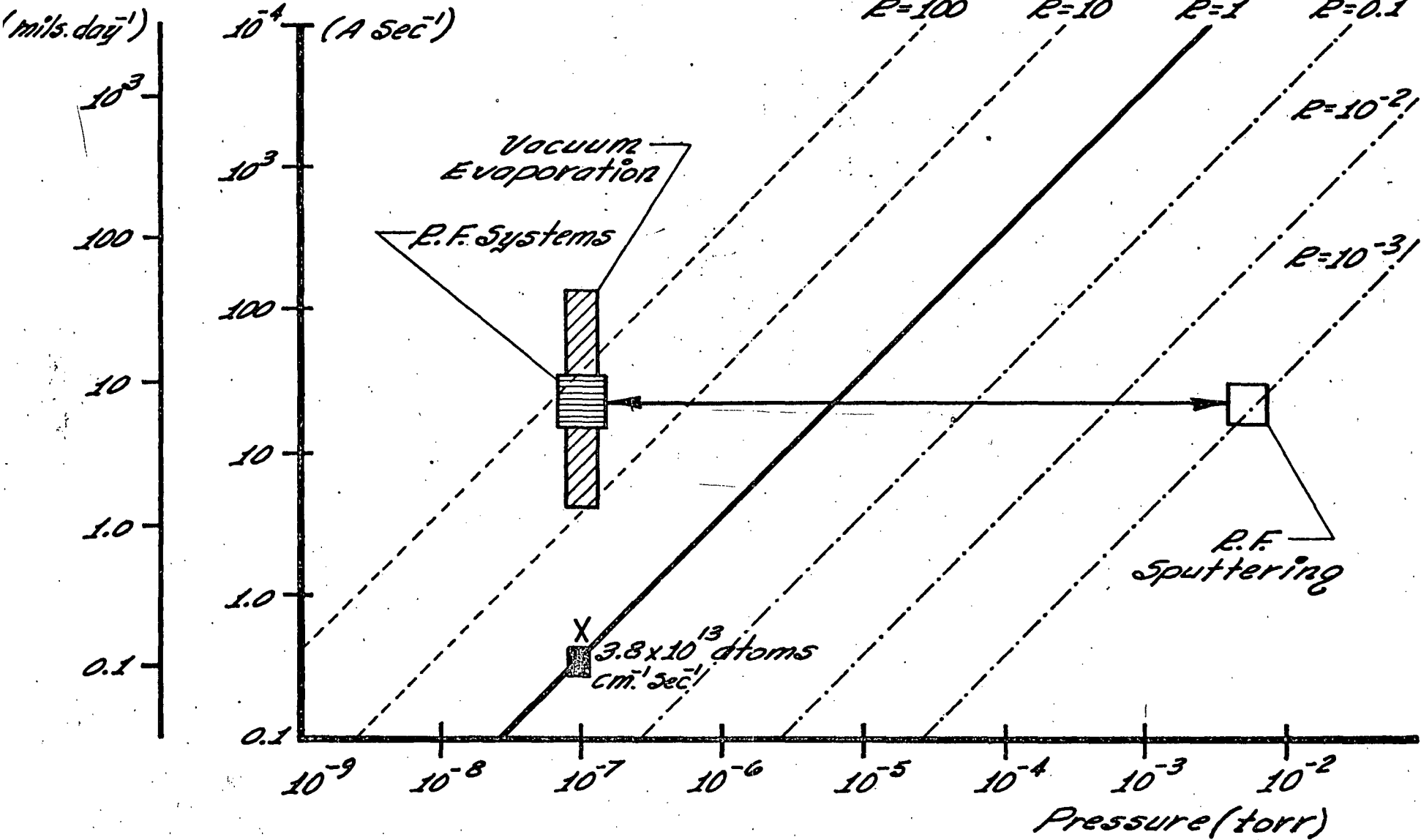
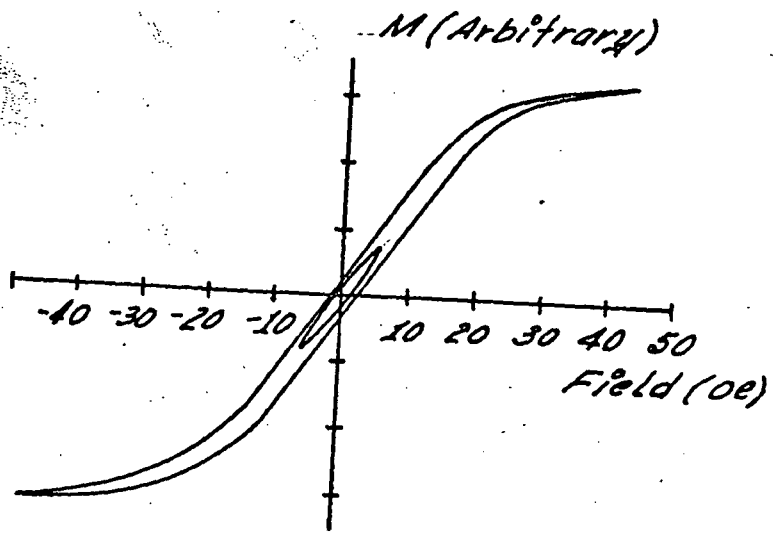
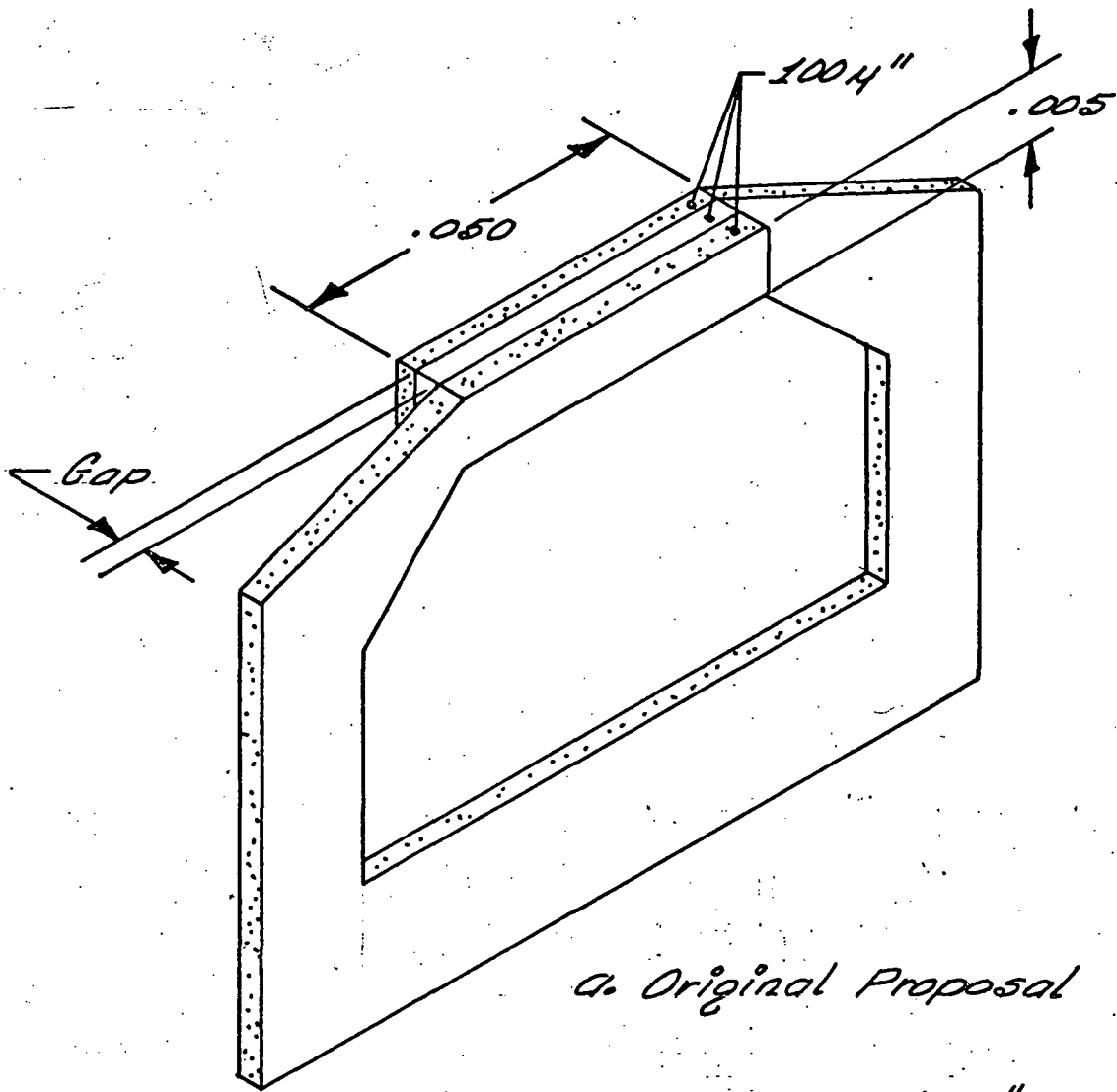


Fig 1

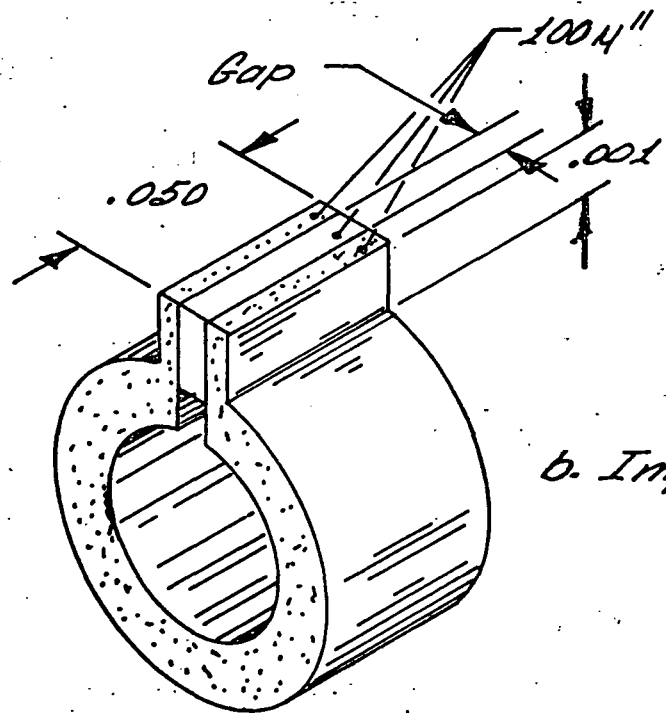


*Open Flux Loop of 44 AlFeSi Film Deposited On
Quartz Coated Palladium & Annealed At 800°C*

Fig 2



a. Original Proposal



b. Improved Geometry

Fig 3 - Magnetic Circuit

Deposited
Magnetic Film

Ferrite

Grinding Line

Ceramic

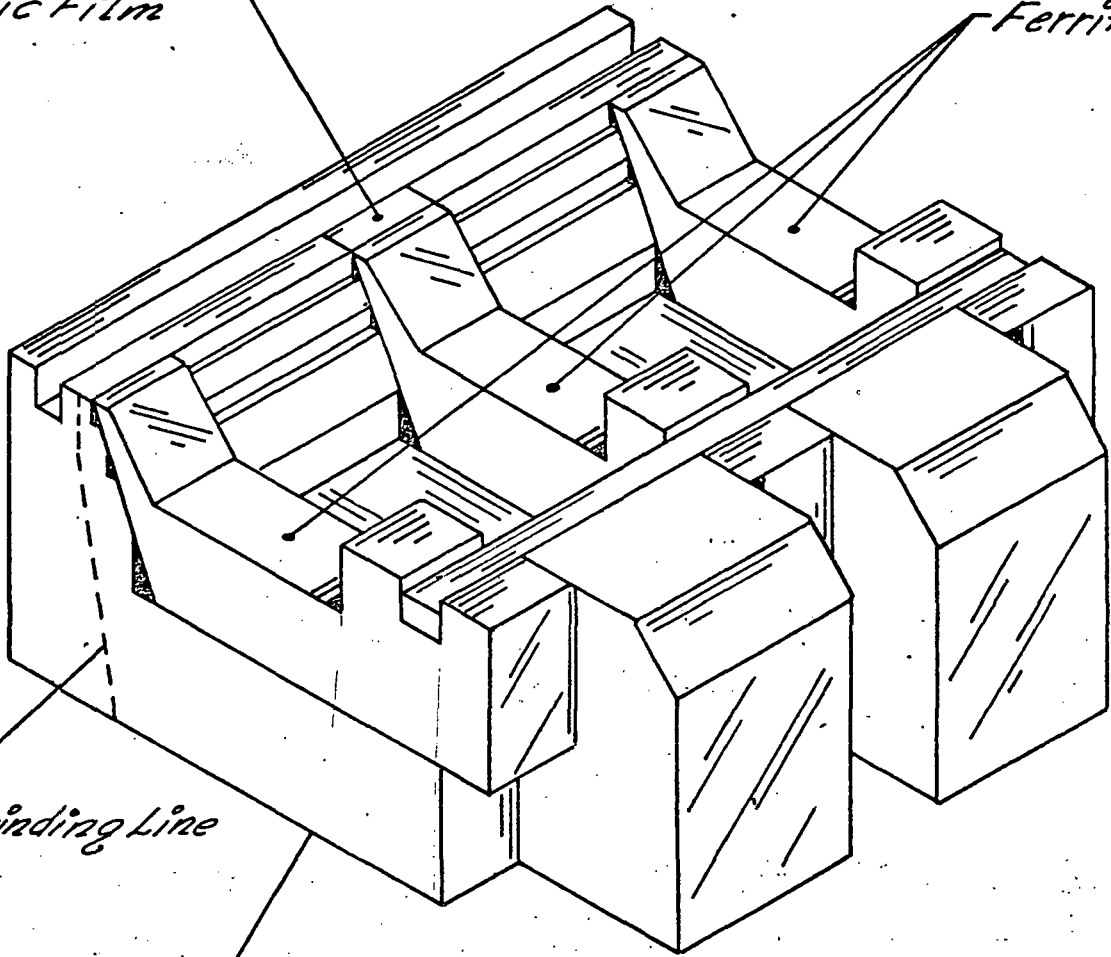
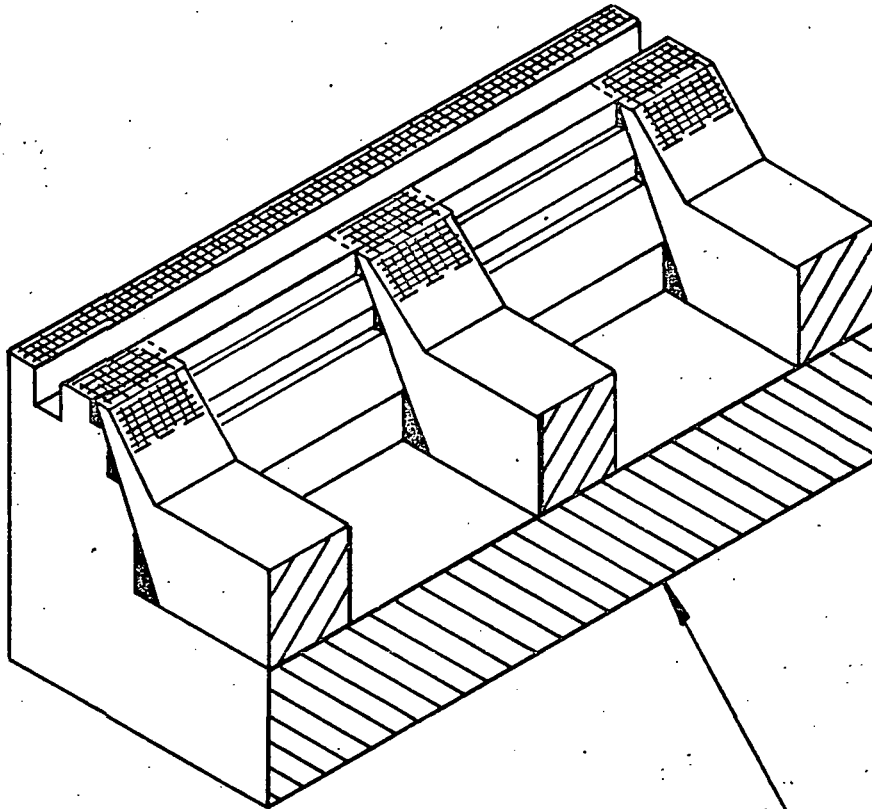


Fig 4 - Half Of Head Assembly



Area 'A'



Section View
See Figure 4

Defining Area 'A' Coated With Ni-Fe & Cr Films

Fig. 5

O.P. (1V) Peak-Peak

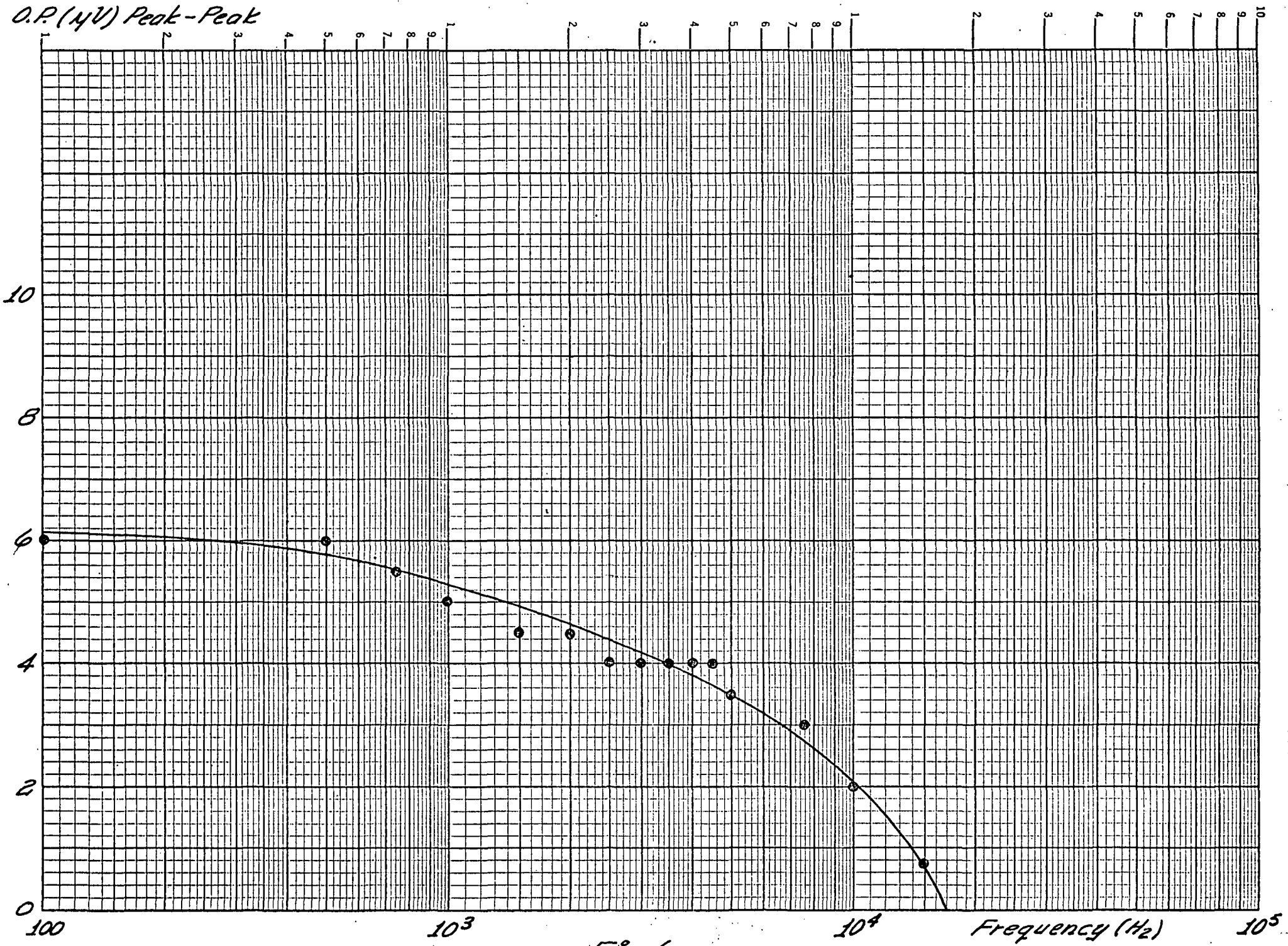


Fig. 6

O.P. (4V) Peak-Peak

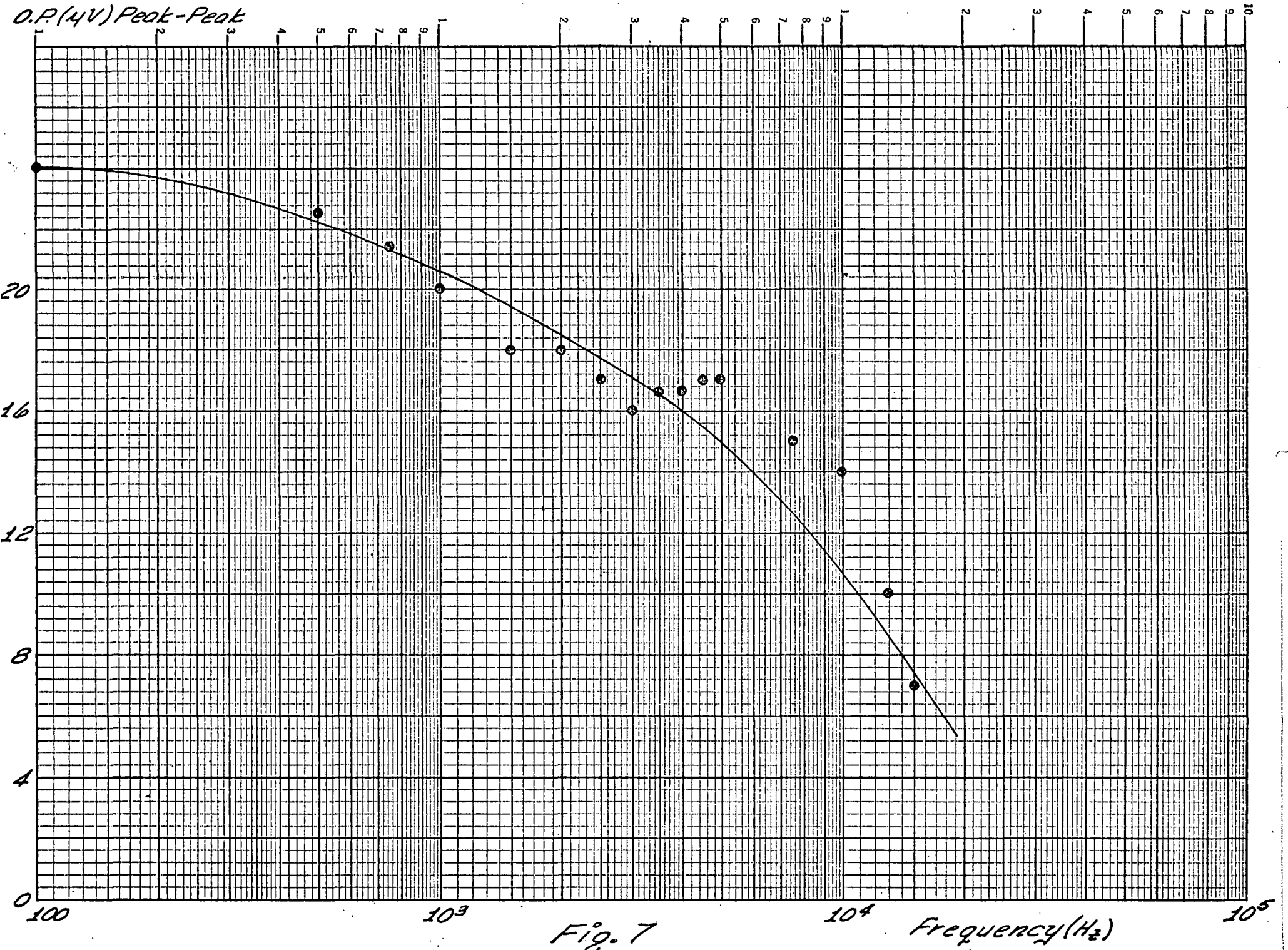


Fig. 7

Frequency (Hz)