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UNION CARBIDE NUCLEAR COMPANY

Division of Union Carbide Corporation

Post Office Box X

Oak Ridge, Tennessee

ORNL
CENTRAL FILES NUMBER

58-2-3

DATE: February 14, 1958
SUBJECT: Development of a Fast-Release Electromagnet
for Pool-Type Research Reactors
TO: E. P. Epler
FROM: C. Michelson

COPY NO. 51

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ABSTRACT

This report is intended to supplement work reported in ORNL-CF-57-9-48 "Design and Experimental Evaluation of Electromagnets for Research Reactors." Included in this present document are additional experimental data and observations of the design parameters and physical configurations which lead to faster-release cylindrical flat-faced electromagnets. Detailed drawings and operating characteristics are presented for an electromagnet suited to the requirements of a pool-type research reactor using either gravity drop or additional accelerating force. This electromagnet embodies the experimentally developed techniques for attaining fast release.

I. INTRODUCTION

In the pool-type research reactor, an electromagnet is the closing link between the instruments which sense a power or nuclear excursion, and the safety rod which stops it. The first requirement of this magnet, from a safeguards point of view, is that it release the safety rod within a specified length of time after initiation of a scram signal, regardless of the magnet current. From an operational point of view, it is also desirable that this magnet not release during such non-nuclear incidents as jars or vibrations, or become inoperative due to dirt on the contact surfaces or misalignment conditions.

The following report deals with the development of such an electromagnet for pool-type research reactors using either gravity or additional accelerating force.

1.1 Design Objectives

Before undertaking this work the following design objectives were assigned:

Accelerating Force (including rod weight)	12 to 77 lbs.
Maximum Zero Power Current	60 ma.
Minimum Excess Holding Force at Zero Power*	50 lbs.
Maximum Release Time at Zero Power	10 msec.
Maximum Release Time at 150 ma.	15 msec.
Minimum Stroke for Free Fall**	0.015 in.
Minimum Stroke with Accelerating Mechanism	0.005 in.

* Excess Holding Force = Magnet Holding Force - Accelerating Force.

** Stroke = Maximum Uniform Air Gap Through Which Magnet Can Exert Accelerating Force with 60 ma. Magnet Current.

This magnet must be adaptable to any accelerating force in the above range with no alterations to the magnet other than a change in the built-in air gap. The release time must not increase more than 50% for the same accelerating force when operating under water. The peak surge voltage during magnet current interruption must be less than 1650 v.

The selected range of accelerating force was based on the results of accelerated rod drop experiments and analogue simulator studies reported in the literature². The accelerating devices now being considered fall within this force range. The minimum excess holding force at zero power was a value which, by experience, was considered sufficient to stabilize the safety rod against most shocks or vibrations.

The maximum zero power current value is the recommended continuous operating level for an ORNL Magnet Amplifier. The maximum operating level for this instrument is 100 ma. This is considered a safe level, but not recommended for continuous operation. However, it can be used to maintain continuity of operation in the event a magnet is required to operate with a temporary air gap due to dirty contact surfaces or misalignment. The maximum uniform air gap through which a magnet can remain operable with a zero power magnet amplifier current of 100 ma. is called the magnet stroke. This stroke is considered a good measure of possible effects of dirt or misalignment. A long stroke is specified only for free fall. With accelerating mechanisms the magnet lift tube and safety rod both have accurate guide bearings near the magnet, thus assuring near perfect alignment and alleviating the problem of bent lift tubes. The only allowance then required is for dirty contact faces (0.005-in.).

The specification of maximum release time was based on analogue computer studies² which evaluated the additional safety derived from very short release times, particularly with accelerated rods. The release time at 150 ma. was specified in order to be certain the release time did not increase appreciably with large overload currents.

1.2 Magnet Power Supply

The magnet power supply used during this study was a standard ORNL Magnet Amplifier. The operating characteristics of this instrument are discussed in detail in Section 1.2, Reference 1, and in the literature³.

1.3 Measurement of Holding Force and Release Time

The holding force and release time characteristics were measured by the methods outlined in Section 2.1, Reference 1. The pulsed-current technique used to measure release time yielded results which are consistent with the following definition of release time:

Release time is defined as the total elapsed time between the initiation of a sigma bus voltage sufficient to drive the magnet amplifier current to zero at steady state, and a movement of the magnet armature which is just sufficient to prevent retraction by the magnet when the sigma bus voltage is returned to its initial value. This release time includes estimated electronic delays of less than one millisecond.

Magnet release time thus has two components. One component is the time required for the magnetic field to decay to the armature release point. The second component is the time required for the armature to pass just beyond the fully retracting influence of the magnetic field as the magnet

current is re-established. This second component includes magnetic and hydraulic effects which appear in the neighborhood of the magnet face as the armature starts to move. (See Section 2.2).

The release time, as measured by this technique, was found experimentally to be essentially equal in value to the release time as measured by the break-away technique (break of electrical contact between armature and magnet). The estimated error was less than minus 5%, for release times up to 30 msec.

1.4 Magnetic Materials

This report considers the use of only two magnetic materials: Armco Ingot Iron ($\sim 100\%$ Fe), and Allegheny Ludlum Ferronickel (53% Fe, 47% Ni). Unless otherwise noted, all parts (poles, yoke, armature, etc.) of the particular magnetic circuit under test were fabricated from the same bar of magnetic material.

II. DESIGN

The design optimization procedures outlined in Section 4.7, Reference 1, were followed in selecting physical dimensions for the design prototype shown in the appendix. This design procedure satisfied space limitations, and current, force, and stroke requirements, but the requirements for fast release had to be resolved by experimental development.

2.1 Design for Fast Magnetic Release

In order to obtain fast magnetic release it is necessary to decay the magnetic field quickly. Since the magnet core is a good electrical conductor, and is linked by a large percentage of the flux lines, eddy currents are induced in the core whenever the magnetic field changes. These currents, in turn, establish a magnetic field which tends to oppose the change, thus, in effect, delaying it. The eddy current power density (P_{de}) which results from an original uniform flux density (B_0) decaying uniformly with an initial function of time ($f(t)$), in a right circular cylinder of radius (r_1) and resistivity (p), is: (Sect. 2.5, Ref. 1)

$$P_{de} = \frac{B_0^2 r_1^2}{8p} \left(\frac{df(t)}{dt} \right)^2 \quad (1)$$

From this equation it can be seen that, for a given original flux density and decay function, a reduction in eddy current power density can be attained by increasing the resistivity of the pole material or decreasing the pole radius.

Effect of Core Resistivity

The effect of core resistivity was determined by using two magnet cores of identical physical dimensions (Fig. 17), but different magnetic materials. The first core was fabricated from Armco Ingot Iron billet ($P = 4.2$ microhm-inches)⁴ and fully heat treated in a hydrogen atmosphere at 1650° F. The second core was fabricated from an Allegheny Ludlum Ferronickel bar ($p = 18.0$ microhm-inches)⁴, and similarly heat treated.

The operating characteristics of these cores with a 12 lb. safety rod are shown in Figure 1. The greater holding force per unit current for the ferronickel core is attributed to its higher permeability at low flux density, as shown in Figure 2. Since the ferronickel saturates at a lower flux density, the force curves eventually cross over. In each case the release time saturates with the holding force. The shorter release time for ferronickel is attributed to its higher resistivity, as predicted by Equation 1. Ferronickel reduces the release time by a factor of three for the same gap and initial holding force.

The effect of core slotting was determined for the same ferronickel and ingot iron cores. The maximum practical number of slots through the core assembly was found to be four. These slots segmented the inside and outside poles into octants. The design of the core assembly (Fig. 17) allowed the slots to extend from the magnet face to beyond the pole tops, thus magnetically separating the assembly into eight individual magnets with a common exciting coil.

Figure 3 shows the effect of slotting a solid ingot iron core assembly with a 0.020-inch air gap on the center pole. Similar data for a solid ferronickel core with a 0.005-inch uniform air gap is given in Figure 4.

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Fig. 1. Solid Cores—Ingot Iron and Ferronickel.

Magnetic Characteristics of Ferronickel and Ingot Iron.

FIGURE 2

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Fig. 3. Ingot Iron Core—Solid and Slotted.

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Fig. 4. Ferronickel Core - Solid and Slotted.

The selection of air gaps is discussed in Section 2.3 of this report. The small loss of holding force at a given current is, in each case, due to a 20% reduction in cross-sectional area after slotting.

A good comparison of solid and slotted pole construction can be obtained by plotting release time vs. holding force, as shown in Figure 5. In this figure the reduction in release time from solid ingot iron to solid ferronickel is a factor of two due to a more favorable air gap on the ingot iron core (See Sect. 2.3). The reduction in release time from solid to slotted ingot iron is about a factor of three; a factor of two in the case of ferronickel. Note, the percentage reduction in release time gained by slotting is greater than the reduction obtained by increased resistivity, as predicted by Equation 1.

2.2 Design for Fast Hydraulic Release

The possibility of hydraulic effects contributing to a slow initial rate of magnet armature movement was reported earlier (Sect. 2.13, Ref. 1). Additional tests have confirmed these observations and indicated a need for further study.

Since most magnet design specifications call for small physical size but large holding forces, it is necessary to design the magnet with a very small magnetic air gap. As a result, the magnet armature must be in near-perfect contact with the magnet face, thus excluding water from the contact surfaces. When such contact surfaces are separated, a void forms. A pressure differential then appears relative to the underside surface of the armature. The resulting decelerating force on the armature is sufficient to measurably retard armature movement. Delays of several hundred milliseconds have been observed in the laboratory for matched surfaces. This

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Fig. 5. Ferronickel and Ingot Iron Cores—Solid and Slotted.

vacuum effect is measurable even in air. One possible solution of this problem is to prevent intimate contact of the metallic surfaces; but restrictions on the total allowable magnetic air gap limits this. Therefore, other methods of reducing the hydraulic delay effect must be utilized.

One mechanism for reducing the hydraulic delay effect is to eliminate all metal-to-metal contact which is not essential to the magnetic circuit. This, in effect, is the purpose of the annular groove in the armature shown in Figure 20, and in the magnet can bottom shown in Figure 18. The contact surface on the armature is larger than on the can face in order to allow for some axial misalignment. The holes in the armature equalize the water pressure in the annular groove with respect to the surrounding water pressure. Since the mechanism for filling any created void is water flow, the annular groove speeds up this flow by providing shorter path lengths between any potential void point and the surrounding water.

When a given magnet design requires some permanent air gap, this can be advantageously introduced at the center pole of the magnet can, thus further reducing the amount of metal-to-metal contact. However, the potential hazard of unauthorized removal of the magnetic air gap must be carefully considered, as discussed in Section 2.9, Reference 1, and in Section 2.3, this report.

The increase in release time resulting from under water operation of the slotted ferronickel core is shown in Figure 6. The rod weight of 10.5 lbs. was maintained constant by adding mass during the under water test. Since completing this test, additional modifications have been made to the magnet can and armature (as per drawings in appendix) to improve the under water operating characteristics. The maximum increase in release time for

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Fig. 6. Slotted Ferronickel Core - Under Water Release.

this new design with a 12 lb. rod under water is now about 20%. As additional accelerating force is added, the under water response rapidly approaches the dry release characteristics.

Because of the intricate shape of this new armature, ferronickel is the only suitable structural material. Ingot iron does not exhibit inherent corrosion resistance and cannot be plated satisfactorily when fabricated with sharp edges, holes, etc. The ferronickel armature should be annealed to improve its magnetic characteristics.

2.3 Permanent Air Gap Requirements

A finite permanent air gap is required to overcome the coercive effects discussed in Section 1.3, Reference 1. The coercive intensity of ingot iron is over ten times that of ferronickel (Fig. 2), thus requiring a larger built-in air gap to overcome the coercive force. With ferronickel the coercive effects disappear for uniform air gaps of 0.005-inch or larger, as shown in Figure 7. A uniform air gap of 0.010-inch is required for ingot iron (Sect. 2.4, Reference 1). In a practical operating situation, the release time of ferronickel increases appreciably only for air gaps near zero, as shown in Figure 13. For a similar operating situation the release time of an Ingot Iron core may become infinite (Sect. 2.7, Ref. 1). Therefore, any built-in air gap on an ingot iron core must be placed where it cannot be easily reduced or removed.

2.4 Magnet Can Design

The magnet can shown in Figure 18 utilizes a thick ferronickel bottom, instead of a thin pure nickel diaphragm as used in earlier designs (Sect. 1.1, Ref. 1). The force advantage, for a given current, gained by using

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Fig.7. Slotted Ferronickel Core—Release Time, Variable Air Gap.

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Fig. 8. Magnet Can Bottoms—Iron and Nickel.

a high permeability material such as ferronickel or ingot iron is shown in Figure 8 (also Sect. 2.11, Ref. 1). By avoiding a rapidly saturating material such as pure nickel, it is possible to obtain considerably better force characteristics within the range of the magnet amplifier. Consistently better fits between the magnet face and can are also possible, even after repeated dismantling of the magnet assembly. Magnet designs calling for small diameters, but large holding forces, can benefit considerably from this design. Further, this design allows extensive alterations or additions to the magnet face for new types of clutch switches, etc., without impairing its magnetic characteristics or structural integrity.

Ferronickel was selected for this application because of its superior corrosion resistance, combined with excellent magnetic properties. Ingot iron lacks the desired corrosion resistance. Since the permeability of ferronickel equals or exceeds that of ingot iron for most flux densities used, the holding force characteristics with a ferronickel bottom will equal or exceed those shown in Figure 8. The release time will also benefit because of the higher electrical resistivity of the ferronickel.

2.5 Other Design Considerations

A complete set of fabrication drawings for this magnet is included in the appendix. Some additional design considerations entering into the final design selections are discussed below.

Electrical Insulation

At the instant of magnet current interruption, a voltage spike appears across the magnet leads and to ground (Sect. 2.2, Ref. 1). Precautions must be taken to protect the electrical insulation during this surge. The

nylon insulation on the coil leads is rated at 10,000 v. In addition, the lead-in wires are brought out of the magnet core assembly through magneto tubing (7000 v). The magneto tubing centers the lead-in wire with respect to the holes and conduit, thus assuring maximum insulation to the nearest ground after impregnation with a potting compound.

The magnet coil (Fig. 19) is also designed to offer maximum high voltage insulation. The critical point is the soldered joint between the nylon wire and magnet wire. With this coil design the joint is buried deep in a channel where it is well protected against possible contact with a ground potential surface. The junction is held securely in place by cotton thread. Triple formex wire is specified for the magnet wire to protect the coil against internal breakdown. The coil bobbin is machined from electrical grade phenolic rod (Grade XXX), to insure good high voltage insulation to the grounded inside pole.

As a final protection against the voltage spike, General Electric Thyrite resistors are added to the magnet amplifier. These thyrite resistors increase the release time so their use must be limited. A peak voltage of 1650 v., as measured by an electrostatic voltmeter across a condenser accumulating its charge through a diode, was selected as the maximum allowable surge voltage for this magnet design. All data given in the body of this report are based on a peak surge voltage of 1650 v. obtained by using three G. E. 8355083G1 thyrites in series. The effect on release time of reducing this surge voltage is listed below, for the case of the slotted ferronickel core with 0.015-inch air gap on the inside pole:

<u>Econdenser (volts)</u>	<u>T_r (msec.)</u>
1650	10.0
1400	11.0
850	13.5
750	14.0
680	15.0

If a higher surge voltage is permitted, the release time can be shortened; but the gain is not sufficient to compensate for the possibility of eventual insulation breakdown.

The possibility of moisture condensation in the lift tubes complicates the electrical insulation problem. Moisture condensation can be prevented by evacuating and sealing, or by sealing-in a dry inert atmosphere. Another approach is to protect the electrical assembly by vacuum impregnating with an epoxy resin (Araldite CN-502 - 8% accelerator). This method also offers at least partial protection against small leaks in the seal weld or elsewhere. Since the epoxy resin does not adhere to the nylon lead-in wire, it is necessary to protect against moisture penetration between the nylon and resin by increasing the path length which moisture must travel to reach the soldered joints in the magnet coil. To accomplish this, a four-inch long lead-in conduit vacuum impregnated with Araldite is used. This conduit offers the additional feature of providing a water well in the lift tube to collect condensate, instead of allowing it to form a pool over the lead-in wires.

Annealing

Although annealing is specified during magnet fabrication to relieve welding stresses, it is also required to improve magnetic properties.

An improvement in the shape of the force curve and release time for the ferronickel core is shown in Figure 9. A marked reduction in the coercive intensity of the ferronickel was also observed in the laboratory.

Magnet Support and Lift Tube

The magnet support and lift tube (Figure 20) are designed for use in a rod accelerating mechanism. The heavy construction and double welding is not necessary for a free fall application.

Coil Replacement

The coil in this magnet may be replaced by cutting off the lift tube a short distance above the magnet support, and then cutting off the magnet can seal weld in a lathe. The Araldite potting resin in the core assembly can be removed by burning out in a vented oven. The replacement coil can then be potted into the core assembly. The lift tube requires a new telescopic joint for welding to the magnet support section. A short fill-in piece is required to make up for the lost length required for the new telescopic joint. The magnet can seal weld completes reassembly of the magnet. A final helium leak test is required.

Clutch Switch

The magnet clutch switch assembly is shown in Figure 20. The compression force on the release spring selected for this assembly must be no larger than required to return the push rod after armature release. A larger spring will appreciably reduce the holding force available for a given magnet current and greatly reduce the magnet stroke.

2.6 Design Modification

The core assembly design shown in Figure 17 was adopted because it offered the best opportunity for maximum slotting of all magnetic material

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Fig. 9. Solid Ferronickel Core—Annealing.

in the core. Some simplification of fabrication is possible if the objective of complete slotting is abandoned.

The best alternate scheme of assembly is to fabricate the inside pole and yoke support as a single piece of ferronickel. The outside pole is then attached to the inside pole by furnace brazing. Prior heat treatment at a higher temperature is required to obtain the best magnetic properties. For this design the slots are not cut to the top of the outside pole. A ring of unslotted metal is left to hold the outside pole together. The gain in fabrication ease by this procedure may not be significant, unless adequate welding facilities are not readily available.

The effect on release time of using this alternate scheme of assembly has not been evaluated.

III. PERFORMANCE

The superior performance of ferronickel over ingot iron lead to its selection for the final design shown in the appendix. Since this magnet must operate over a range of accelerating forces, its performance was evaluated for both the free fall and maximum acceleration cases. For intermediate values of accelerating force, only an upper bound on performance was determined (zero air gap case). The required built-in air gap for best performance with a given accelerating force was determined experimentally.

3.1 Free Fall

For the free fall case, a built-in air gap of 0.015-inches is required on the inside pole of the can bottom. The performance characteristics of this design are shown in Figure 10 and summarized as follows:

Accelerating Force	12 lbs.
Zero Power Current	55 ma.
Excess Holding Force at Zero Power	59 lbs.
Release Time at Zero Power	10.2 msec.
Release Time at 150 ma.	15.5 msec.
Stroke	0.020 in.

The release time of this magnet increases 20% when operated under water with a 12 lb. safety rod. This performance closely approximates the design objectives as listed in Section 1.1.

If a reduction of excess holding force is permissible, a considerable improvement in release time can be obtained. For instance, a dry release time of about 5 msec. is possible if the excess holding force is reduced to 30 lbs. (42 lbs. total holding force), as shown in Figure 11. Many

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Fig.10. Free Fall Operating Characteristics.

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Fig. 44. Release Time vs. Holding Force for Free Fall.

pool-type research reactors now operate with this excess holding force, but have an order of magnitude longer release time. In any case, however, the benefits in operating continuity derived from large excess holding forces should not be overlooked.

At this point it should be emphasized that optimum performance cannot be obtained for all holding forces within the range originally specified. Considerable improvement in performance can be obtained if the magnet is designed specifically for a 12 lb. accelerating force.

3.2 Maximum Acceleration

In order to ~~accomplish~~ ^{obtain} a maximum holding force of 77 lbs., it is necessary to remove the built-in air gap. The resulting holding force characteristics for this condition are shown in Figure 12. Data is also given in this figure for the case of 0.005-inch added temporary air gap. The release time which results from removal of the air gap is shown in Figure 13, for various accelerating forces. This magnet is designed to operate with no air gap only at 77 lbs. For smaller accelerating forces the amount of built-in air gap required to give the desired operating characteristics must be determined experimentally. Figure 13 does indicate an upper bound on performance at smaller accelerating forces, or the effect of a change in spring tension on a maximum accelerated mechanism.

One of the desirable features of ferronickel is its short release time even for free fall with no built-in air gap. This is due to the lower coercive force as discussed in Section 1.3, Reference 1, and as shown in Figure 2. The performance of the final design with maximum acceleration is summarized as follows:

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Fig.12. Holding Force for Zero Air Gap.

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Fig. 13. Release Time for Zero Air Gap.

Accelerating Force	77 lbs.
Zero Power Current	54 ma.
Excess Holding Force at Zero Power	53 lbs.
Release Time at Zero Power	4.5 msec.
Release Time at 150 ma.	7.0 msec.
Stroke	0.004 in.

The increase in release time under water is negligible.

The holding force of 77 lbs. represents an upper limit on performance, since it requires removal of all built-in air gap. The release time under this condition is influenced by the coercive force of the ferronickel, as indicated in Section 3.3. If a faster release is desired for this maximum acceleration force, a larger magnet having a small built-in magnetic air gap must be designed.

3.3 Design Extrapolation

Although the magnet discussed in this report was designed only for forces up to 77 lbs., there is some question as to what performance might be expected if a similar design technique is followed on magnets adaptable to larger rods or accelerating forces.

The release time of the present design as a function of holding force to rod weight ratio (for various weights and air gaps) is shown in Figure 14. For a given initial holding force (F_m), the flux density in the core is (B_m). The flux density in the core at the instant a given rod weight (W_r) is released, is (B_r). Since the force produced by a given flux density over the pole cross-sectional area (A) is (B^2A), the holding force to rod weight ratio is independent of area:

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Fig. 14. Release Time for Given Force to Rod Weight Ratio.

$$\frac{\text{Holding Force}}{\text{Rod Weight}} = \frac{B_m^2}{B_r^2} \quad (2)$$

Since the release time (T_r) is linearly related to this ratio, as shown in Figure 14, it can be expressed as:

$$T_r = K_1 \left(\frac{B_m^2}{B_r^2} - 1 \right) \quad (3)$$

The slope of this curve is influenced by the equivalent radius of the core segments and resistivity of the magnetic material (Eq. 1), and by the coercive force effects if the air gaps are small.

The effect of core slotting and change in core resistivity is shown in Figure 5, for the case of constant (B_r) and constant air gap. The effect of small air gaps is shown in Figure 14. Above 0.005-inch uniform air gap this effect disappears for the ferronickel core, as shown in Figure 7.

If the coercive force effects are eliminated by sufficient air gap, the performance curve shown in Figure 14 can be duplicated for larger magnets by operating them at the same flux density and selecting a core geometry and magnetic material which will give the same (K_1) value. For instance, if the pole radius for the new magnet is doubled, the pole area will be four times as large, as will the holding force for the same flux density. If it is assumed the poles of the original magnet (radius r_0) were cut into eight equivalent cylinders, the radius of each cylinder must have been $(r_0 / \sqrt{8})$ to maintain the same cross-sectional area. If the new magnet is to have the same equivalent radius for its poles, and thus the same eddy current power density (Eq. 1), it must be cut into N segments:

$$\frac{r_0}{\sqrt{8}} = \frac{2 r_0}{\sqrt{N}} \quad (4)$$

$$N = 32$$

According to this simplified model, if the poles on the new magnet are segmented into 32 pieces (16 diametral cuts), the performance should be equivalent to the present design. The practical limit on segmenting this larger design appears to be eight diametral cuts.

APPENDIX

Model BSF-3 Fabrication Drawings and Performance

This appendix includes a complete set of fabrication drawings for a Model BSF-3 lifting magnet for swimming pool type research reactors. The free-fall performance characteristics of a typical production model are included for both dry and under water conditions. These characteristics are improved over those shown in the body of this report because of additional design modifications made before fabricating the production model. Addition of the clutch switch increases the magnet current, for a given holding force, about 2 ma., but does not measurably decrease release time beyond the range of experimental accuracy under water.

All performance data on this production model were taken with one G. E. 8355083G7 thyrite resistor connected across the magnet coil. This resistor limited the voltage peak to about 1400 v.

SUMMARY OF MODEL BSF-3 FREE-FALL PERFORMANCE

Under Water with Clutch Switch and 1400 v. Thyrite Protection

Rod Weight	12 lbs.
Zero Power Current	58 lbs.
Excess Holding Force at Zero Power	63 lbs.
Release Time at Zero Power	10.5 msec.
Release Time at 150 ma.	15.0 msec.
Stroke	0.015 in.

FIGURE 15 Photograph of Magnet Assembly

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PARTS LIST				
PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL
A	D-30443	1	Magnet Core Assembly	
B	D-30444	1	Magnet Can Assembly	
C	D-30445	1	Magnet Coil Assembly	
1	D-30446	1	Extension Tube - 10 D. x 1/8 Wall	55T-347
2	D-30446	1	Switch Mounting Collar - 1 1/2 x 1 1/2 x 1 1/2	Alum. 1100
3	Stock	1	Soc. Hd. Cap Screw - #10-24NC-2 x 1 1/8 Lg.	55T
4	D-30446	1	Magnet Support - See Detail	55F-349
5	Stock	4	Soc. Hd. Cap Screw - #10-32NF-2 x 3/8 Lg.	55T
6	D-30446	1	Magnet Armature - 2 1/2 Dia. x 1/8 Thick	Perm. Steel 862
7	Stock	1	Micro Switch - Cat. No. 15E1-6	
8	Stock	2	Rd. Hd. Mech. Screw - #2-56NC-2 x 1 1/2 Lg.	55T302
9	D-30446	1	Spring - .028 Wire Dia. - See Detail	55F304
10	Stock	1	Retaining Ring - # 5133-12-W	55F-420
11	D-30446	1	Push Rod - See Detail	55F-303

LTR	REVISIONS	DATE	APPD	APPD
DRAWING NO. D-30442				
DRAWN	DATE	CHECKED	DATE	APPROVED
R. S. Jones	10-4-57	C. Angel	10-28-57	
DESIGNED	DATE	SUBMITTED	DATE	APPROVED
		C. Angel	10-31-57	

FIGURE 16

- GENERAL SPECIFICATIONS:
1. Break all sharp edges 1/64 max. unless otherwise specified.
 2. The fabricator may choose the type, grade or finish of material unless otherwise specified.
- MACHINE FINISH SPECIFICATIONS:
1. Finish symbols are in accordance with ASA Standard B46.1 - 1947.
 2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
 3. For surfaces not otherwise indicated, roughness height shall not exceed $\sqrt{\text{ }}$.

THIS DRAWING CLASSIFIED	
ALL UNCLASSIFIED	
PER <i>L. Nicholson</i>	
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED	
FRACTIONS: $\pm$	
DECIMALS: $\pm$	
ANGLES: $\pm$	
SCALE: 1" = 1"	

Shim Rod Drive Assembly	D-15558
Main Assembly	D-30425
Magnet Detail Sheet #1	D-30446
(C) Magnet Coil Assembly & Details	D-30446
(B) Magnet Can Assembly & Details	D-30444
(A) Magnet Core Assembly & Details	D-30443
REFERENCE DRAWINGS	DWG. NO.
POOL TYPE CRITICAL ASSEMBLY BLDG. NO. 3010	
MAGNET ASSEMBLY	
OAK RIDGE NATIONAL LABORATORY OPERATED BY	
UNION CARBIDE NUCLEAR COMPANY	
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION	
OAK RIDGE, TENNESSEE	
SUBMITTED	APPROVED
<i>L. R. Jones</i>	<i>L. Nicholson</i>
	<i>F. W. West</i>
	D-30442

APPROVED FOR CONSTRUCTION

PARTS LIST				
PART NO.	DWG. NO.	QTY	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL
B-1	This Sheet	2	Magnet Can Guide Ring - 2 1/2" Sch. #80 Pipe	SST-347
B-2	This Sheet	1	Magnet Can Sleeve - 2" Sch. #80 Pipe	SST-347
B-3	This Sheet	1	Magnet Can Bottom - 2.300 Dia. x 3/16" Thick	SST-347
B-4	This Sheet	1	Magnet Can Seal Ring - 1.975 Dia. x 3/16" Thick	SST-347

Magnet Assembly		D-30444
REFERENCE DRAWINGS		DWG. NO.
POOL TYPE CRITICAL ASSEMBLY		NO. 3010
(B) MAGNET CAN ASSEMBLY & DETAILS		
ONK RIDGE NATIONAL LABORATORY		
OPERATED BY		
UNION CARBIDE NUCLEAR COMPANY		
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION		
ONK RIDGE, TENNESSEE		
DESIGNED BY	APPROVED BY	
DATE	DATE	
11-4-51		
D-30444		

APPROVED FOR CONSTRUCTION

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ORNL-LR-DWG 25251

Fig. 21. Performance of Model BSF-3

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4. H. C. Roters, Electromagnetic Devices, John Wiley and Sons, Inc., New York, 1941.

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