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**MODIFIED FERMI CONTROL ROD LATCH
FOR THE FFTF--REPORT ON THE
DEVELOPMENT AND TESTING PROGRAM**

J. R. McBride

April 1970

**AEC RESEARCH &
DEVELOPMENT REPORT**

*Tables for
R. R. Barick*

TABLE	FIGURE	DATE
99999	3201	JUL 20 1970
90944	325	JUL 20 1970

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FOR THE FFTF--REPORT ON THE
DEVELOPMENT AND TESTING PROGRAM

by

J. R. McBride

Mechanical Engineering Department
Physics and Engineering Division

April 1970

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J. R. McBride

ABSTRACT

A development and testing program was conducted on an electromagnet and latch assembly for the Modified Fermi Control Rod Drive Mechanism Concept proposed for the Fast Flux Test Reactor (FTR). The components tested were designed to the FTR conceptual requirements. The electromagnet was successfully tested in ambient air to determine the load carrying capability (1000 lb) and release characteristics. The latch assembly was successfully tested in water for 5000 latch and scram cycles with a simulated load of 2400 lb. Due to a change in the FTR concept and funding limitations, this development program was terminated in early 1969.

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MODIFIED FERMI CONTROL ROD LATCH
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DEVELOPMENT AND TESTING PROGRAM

INTRODUCTION

One of the control rod drive concepts considered for the Fast Test Reactor (FTR) is the Modified Fermi Concept.⁽¹⁾ This drive concept, derived from the Enrico Fermi Fast Breeder Reactor safety rod drive concept,⁽²⁾ was designed to meet the FTR requirements. In addition, it incorporates improvements in technology made since the Enrico Fermi drive was designed.

The primary advantage of the Modified Fermi Concept is that the poison assembly is released from the drive below the reactor cover for scram. Since this separation takes place below the reactor cover and, therefore, below the control rod seal, there is no possibility for the seal to interfere with the scram. Also, by separating below the reactor cover, the mass, which must be accelerated into the reactor core, is minimized.

To ensure that the Modified Fermi Concept would meet FTR requirements, a development and testing program for critical components was conducted. Under this program, the decelerator, stepping motor-ball screw combination, and the latch assembly underwent development and testing. This report describes the development and testing of the latch assembly.

When the development and testing program for the control rod components was instituted, the design of the reactor was not fixed. Therefore, assumptions were made about the reactor with regard to geometry, environmental conditions and performance requirements. However, under these conditions, the emphasis of the development and testing program was to develop relationships and data that would be useful even if changes were made in the reactor design.

SUMMARY

A control rod latch assembly to operate under FIR conditions and based on the Enrico Fermi Latch concept was designed, constructed, and tested. The Modified Fermi Concept was shown to be feasible for use in the FIR as it was originally designed. Additional development and testing would be required to take this concept from its present state of development to a proven component.

RECOMMENDATIONS

Because of a change in reactor refueling concepts, the Modified Fermi Concept is no longer applicable to the FTR. The present vertical core concept requiring disconnection of the drive extension just above the core and just below the reactor cover is not practical with the Modified Fermi Latch concept.

Unless a change in the refueling concept makes the Modified Fermi Latch concept usable, no further development and testing work is recommended.

DISCUSSION

LATCH CONCEPT

Description of Design

The Modified Fermi Control Rod Assembly (Figure 1) consists of three major sections: the drive, drive-extension, and poison sections.

The poison section is coupled to the lower end of the drive extension section with a mechanical latch. The whole assembly is raised and lowered with a translating nut type ball screw actuator powered with a stepping motor.

The latch and the electromagnet are part of the drive extension section detailed in Figure 2. The middle portion of the drive extension assembly has been removed from the illustration to better show the relationship between the latch and electromagnet. The electromagnet assembly is located in the drive cavity which is near the top of the reactor and above the shield plug. The latch itself operates below the pool surface in liquid sodium.

The latch consists of a cam, latch rod, latch fingers, extension housing, and cocking tube. Three latch fingers are cammed in over the latch spool to couple the poison section to the drive extension section. The latch spool is attached to the poison assembly with a spool bolt (Figure 3). The mating surface between the bolt and the spool is spherical so that the spool may pivot to accommodate a small amount of angular misalignment between the fingers and the spool.

The latch fingers are supported in a groove in the drive extension. Each finger has two conical surfaces, one where it contacts the cam and the other where it contacts the latch spool. The corresponding mating surfaces on the cam and spool are also conical. The fingers are loosely retained

FIGURE 1. Modified Fermi Control Rod Assembly

SK-3-13288

BNWL-1335

FIGURE 2. Drive Extension Section Details

FIGURE 3. Latch Spool and Spool Bolt Details

radially by the cocking tube which is part of the drive extension tube. The cocking tube also guides the cam and has an internal step to limit the downward movement of the cam.

The outside diameter of the cam is relieved, leaving only a narrow shoulder at each end to position it radially in the cocking tube. The shoulders themselves have shallow reliefs cut in their periphery. The cam is relieve in this manner to allow sodium to flow, which limits crud buildup and prevents sodium from being trapped when the assembly is removed from the sodium pool.

The connection between the cam and latch rod is made flexible to avoid transmitting bending loads to the latch rod in the event that the cam is misaligned. The lower end of the latch rod is provided with a modified Acme screw thread and the guide through which it passes has axial grooves. This arrangement serves to reduce contact area between the sliding parts, provides a flow path for sodium, and the threaded shaft acts as a scraper to clear any accumulation of crud that might build up.

The electromagnet assembly (Figure 2) consists of an electromagnet, armature, delatch assist spring, magnet backup spring, and limit switches. The latch rod connects the latch cam to the electromagnet armature. A bellows seal isolates the electromagnet assembly from the argon gas-sodium vapor atmosphere that exists above the sodium pool.

The latching sequence is illustrated in Figure 4. With the poison section uncoupled and bottomed in the dashpot, the extension section is driven on the poison section scram assist spring follower and begins to compress the spring. Driving further down, the latch cam contacts the spool bolt (Figure 4a).

The extension is driven further down causing differential motion between the latch fingers and cam, closing the fingers over the spool. At the same time, the electromagnet, which is part of the drive extension, moves down to contact the armature. When the extension has moved 0.75 in. down from the

FIGURE 4 Latching Sequence

point of initial contact with the cam (Figure 4b), the electromagnet makes contact with the armature. To ensure good contact between the electromagnet and armature, the extension drives down another 0.25 in. compressing the electromagnet backup spring and actuating the limit switches which stop the drive and energize the electromagnet (Figure 4c). The drive is reversed and withdrawn 1 in. to the rod seated position (Figure 4d).

The scrambling sequence begins with the poison section coupled to the drive extension and raised to the operating position. Upon receipt of a signal to scram, the electromagnet is de-energized. The combination of the latch rod assembly weight, delatch assist spring force, and the resultant downward force on the cam caused by the outward force on the latch fingers causes the cam to move downward with respect to the fingers. As the cam moves downward, the acceleration spring and weight of the poison section pull the latch spool out of the fingers. The cam moves further downward, and cams the fingers out from the inside so that the fingers will fit over the spool when subsequently moved down for relatching.

Latch component materials play an important role in the successful operation of the latch due to the severe environment in which they operate. For the most part, materials used in the Enrico Fermi latch were specified for use in the Modified Fermi.

Most of the moving components of the latch were made of Stellite 6B⁽³⁾ which is a cobalt-base alloy recommended for handling extreme conditions of wear, abrasion, and heat. Latch components made from Stellite 6B are the cam, fingers, finger carrier, and spool. The spool bolt, latch rod, latch rod pin, cocking tube, and drive extension were made from Type 304 SS.

Most of the electromagnet assembly components were made from Type 304 SS. The electromagnet core and armature were made from Armco magnetic ingot iron⁽⁴⁾ which was selected for its magnetic properties. The coil wire was 28% nickel-coated copper-insulated with a ceramic covered with a thin silicone film.⁽⁵⁾ This wire is rated for continuous service at 500 °C (932 °F).

Design Requirements

At the beginning of the program, requirements for the latch were indefinite. To provide a basis for the design, tentative specifications were established based on the best information available (Table 1).

TABLE 1. Latch Assembly Design Requirements

Maximum Diameter		
Latch Section, in.		4
Electromagnet Section, in.		4
Latch Load		
Normal Conditions		
Poison Assembly Weight	200 lb	
3 g Scram Assist Spring Force	<u>600 lb</u>	
		800 lb
Stuck Rod		
Drive Capacity	1300 lb	
3 g Scram Assist Spring Force	<u>600 lb</u>	
		1900 lb
Environment		
Latch, °F		1200 (Sodium)
Electromagnet, °F		1000 (Argon)
Life, yr		20
Number of Cycles		2000

TEST PROGRAM

Testing Objectives

Objectives of the test program were to determine:

- The effects of cycling under load on the latch.
- The relationship between latch rod force and latch load and the effect of cycling upon this relationship.
- Electromagnet holding capacity and release time as a function of coil current for different air gaps.
- The capability of the latch to accommodate radial misalignment between it and the latch spool.
- The effect of elevated temperature on the capabilities of the electromagnet.
- The release time, load capacity, and reliability of the electromagnet-latch combination.

Objectives 4 through 6 were not accomplished because of a discontinuance of the test program.

Description of Latch Testing Equipment

Figure 5 shows the test stand that was constructed to test the latch. Figures 6 and 7 show the latch components tested while Figure 8 depicts them partially assembled.

The test stand consists of a frame carrying a subframe on bearings which allowed the test assembly to be tilted at angles up to 30° from the vertical. The simulated guide tube was carried in this subframe, and the latch test assembly slid up and down inside the guide tube. At the lower end of the guide tube, an air cylinder (spool retraction cylinder) was mounted with the piston rod pointed up into the tube. A prototype latch spool was mounted on the end of the piston rod. The air cylinder is attached in such a manner that it may be rotated to get radial misalignment with respect to the latch from 0 to 0.200 inches.

Neg 0684709-2

FIGURE 5. Latch Test Stand

Neg 0684334-3

FIGURE 6. Latch Components

Neg 0684334-2

FIGURE 7. Latch Component Details

Neg 0684334-1

FIGURE 8. Latch Components Partially Assembled

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Two hydraulic cylinders mounted on the upper end of the guide tube on the subframe raised and lowered the latch assembly in the guide tube. An air cylinder on the upper end of the latch assembly (latch rod cylinder) actuated the latch as the electromagnet would. The test stand was designed so that the electromagnet is dimensionally interchangeable with the latch rod cylinder. In this manner, the stand could also be used to test the latch-electromagnet combination.

To cycle the latch, the following sequence was followed. With the latch assembly raised, the spool retraction air cylinder was energized, extending the spool up into latching position. The latch was then lowered with the hydraulic cylinders down over the spool. When the cam contacts the spool the fingers were closed in over the spool. When the fingers were fully closed over the spool, the latch-rod cylinder was energized to hold the fingers closed over the spool. The hydraulic cylinders were then raised to load the latch. When the load was applied to the latch, the spool-retraction cylinder valving was switched so that when the latch was released, the spool snapped down out of the fingers just as a scrambled poison assembly would in the reactor. At the same time that the valving was switched on the spool retraction cylinder, a timer was started. Load on the latch was held until the timer completed its preset cycle. With the latch rod cylinder then de-energized, the cam was allowed to drop and the fingers were free to open, releasing the spool which was retracted downward by the spool retraction cylinder. The hydraulic cylinders again raised the latch assembly to begin another cycle.

Latch parameters that could be varied were: latch load, latch rod holding force, spool retraction force, rate of latch travel, cam stroke, and latch-spool radial eccentricity.

Description of Magnet Test Equipment

Figure 9 shows the test stand employed to test the electromagnet; Figure 10 shows the major components of the electromagnet assembly.

To test the electromagnet, the armature was raised up into position with the load-lift cylinder pressurized by a hand powered hydraulic pump. After the armature contacted the face of the electromagnet, the electromagnet was energized. The hydraulic cylinder valving was then reversed, and a downward load was applied to the electromagnet. Load on the electromagnet was measured with a pressure gage and a pressure transducer. The output signal of the pressure transducer was displayed on an oscilloscope with an image retaining tube and was recorded with a camera. Electromagnet parameters that could be varied were: field excitation, load, and nonmagnet gap between armature and electromagnet.

Neg 0694611-2

FIGURE 9. Electromagnet Test Stand

Neg 0694611-1

FIGURE 10. Electromagnet Components

Test Results

Results of tests performed on the latch and electromagnet will be summarized in this section. Appendix B contains the complete results of tests performed.

Latch Tests Summary

The latch while immersed in water was cycled successfully for 5000 cycles at a load of 2400 lb. The condition of latch components was checked approximately every 1000 cycles by static tests to determine required latch rod force for a range of latch loads and by a visual examination of the latch components.

Cycling affected the latch in several ways. First, there was visible deterioration of the load bearing surfaces of the latch components, particularly, the cam and fingers. This was readily apparent at the first examination performed after only 532 cycles (Figures 11 and 12). A wear pattern developed on the latch finger-spool contacting surface (Figure 11) which indicated that the spool and fingers were not making proper contact. The nature of the pattern indicated that the fingers were being cammed too far in as shown in Figure 13. Full area contact between the fingers and the cam was achieved by reducing the cam stroke from 0.750 to 0.700 in.

In static testing, the latch for required latch-rod holding force as a function of latch load, an interesting phenomenon was discovered. Cycling the latch caused the required latch holding force for a given latch load to decrease, indicating an increase in coefficient of friction. The coefficient of friction would be expected to increase with deterioration of the sliding surfaces resulting from galling and wear. What was unexpected is that if the latch parts were left idle for a few days and the latch then retested, the coefficient of friction had decreased nearly to its original value.

Neg 0690028-1

FIGURE 11. Close-up of Wear Pattern on Spool
Contacting Surface of Latch Fingers

Neg 0690028-4

FIGURE 12. Wear Pattern on Latch Spool

FIGURE 13. Improper Contact Between Finger and Spool

It was theorized that the wear on the latch parts increased friction by removing the surface oxide layer, which would then reform if these surfaces were left undisturbed for a period of time. To test this theory the latch was left idle for a period of days and then statically tested for latch rod force as a function of latch load. The latch was then cycled for 148 cycles and retested. Figure 14 shows the considerable decrease in required latch rod holding force. In fact, Test A results show a decline in slope as the latch loads were successfully reduced indicating an increase in friction during the test. If the latch was operated in sodium this phenomenon probably would not occur because sodium removes the oxide layer from materials rather than creating it. Therefore, results obtained after cycling would be more nearly like the results expected from sodium tests.

FIGURE 14. Latch Rod Holding Force Versus Latch Load

Electromagnet Tests Summary

Fabrication and testing of the electromagnet presented several difficulties which were successfully overcome.

Acquiring suitable high temperature magnet wire and winding it successfully proved difficult. The first spool of wire ordered arrived after four months in two pieces. The vendor was totally unsympathetic with our need for a continuous length of wire so payment was stopped and the wire returned. This wire was rated for 1000 °F.

Another vendor supplied wire rated at 500 °C (932 °F). A poor bond between insulation and wire made it impossible to wind a coil that didn't short. The vendor had to send three different spools of wire before a good coil was wound. The coil was 644 turns, which represents a 70% packing factor, and according to the wire manufacturer, this wire can be wound to a maximum packing factor of 74%. Although this wire was made to work, its insulation is very fragile and is marginal at best. A better wire would be needed to meet reliability requirements.

The original electromagnet release time measuring system employed a switch to simultaneously break the coil circuit and start a high speed counter. A miniature limit switch was used to stop the counter when the armature dropped away from the face of the electromagnet. With electromagnet release times of less than 10 msec, the observed time delays and variations in the switches of 5 msec or more were unacceptable.

The time measuring system finally evolved employed an oscilloscope with an image retaining type tube, a camera to record the image, and a pressure transducer connected to the load cylinder. With the shutter on the camera open and the electromagnet loaded, the oscilloscope was triggered to provide a reference horizontal line indicating constant

pressure. The remote triggering circuit was then armed. When the electromagnet coil current was interrupted with a switch, an instantaneous high voltage spike was induced which triggered the oscilloscope to scan. The armature was assumed to have been released from the electromagnet when load cylinder pressure started to fall off. By knowing the scan rate of the oscilloscope, the release time could then be measured directly from the photograph of the oscilloscope display (Figure 15).

FIGURE 15. Sample Oscilloscope Trace for Determination of Release Delay

Theoretical and actual breakaway force versus coil current for armature gaps of 0, 0.001, and 0.002 in. are shown in Figure 16. The difference between theoretical and actual

FIGURE 16. Theoretical and Actual Breakaway Force Versus Coil Current for Different Nonmagnetic Gaps

breakaway force is probably the result of differences between theoretical- and actual-material magnetic properties and unaccounted-for resistances to magnetic flux in the magnetic circuit. Because of its conservative design, the electromagnet still has more than sufficient holding capacity.

Release time of the electromagnet versus magnet load for 0 and 0.001 in. nonmagnet gaps are shown on Figures 17 and 18, respectively. As shown, there should be no difficulty in achieving an electromagnet release time of less than 10 msec over the full range expected loads. This is a very small delay considering an estimated delatch delay of 46 msec (Reference 1, p. C-23) and an estimated 600 msec for the poison to travel into the core.

FIGURE 17. Armature Release Delay Versus Magnet Load for 0 Shim and Different Coil Currents

FIGURE 18. Armature Release Delay Versus Magnet Load for 0.001 in. Shim and Different Coil Currents

REFERENCES

1. *J. R. McBride and B. C. Fryer. FFTF Modified Fermi Control Rod Drive Mechanism Conceptual Design Study, BNWL-970. Battelle-Northwest, Richland, Washington, June 1969.*
2. *J. W. Hess. Design and Operating Experience with the Control and Safety Rod Drive Mechanisms for the Enrico Fermi Fast Breeder Reactor, APDA-301. Atomic Power Development Associates, Inc., Detroit, Michigan, June 1, 1966.*
3. *Union Carbide Wear-Resistant Alloys Bulletin F-30,133B, Union Carbide Corporation Stellite Division, Kokomo, Indiana, 1965.*
4. *Armco Magnet Ingot Iron...for D-C Applications. Armco Steel Corporation, Middletown, Ohio, 1963.*
5. *REA Guide to CEROC and TETROC. REA Magnet Wire Company, Inc., Fort Wayne, Indiana.*

APPENDIX A
TEST APPARATUS

APPENDIX A
TEST APPARATUS

Latch Test Stand

Drawings* SK-3-13470, Sheets 1 and 2
SK-3-13378, Sheets 1 thru 5
SK-3-13230, Sheet 1

Load Cylinder Pressure Gauge

Heise 0-600 psig calibrated 0.1% F.S.

Latch Rod Cylinder Pressure Gauge

Heise 0-300 psig calibrated 0.1% F.S.

Electromagnet Test Stand

Drawings* SK-3-13475, Sheets 1 and 2
SK-3-13476, Sheet 1

Load Cylinder Pressure Gauge

Heise 0-800 psig calibrated 0.1% F.S.

Load Cylinder Pressure Transducer

CEC 4-313-0001 0-500 psig

Oscilloscope

Tektronix 453, Serial No. 35144

* SK-Numbers refer to Pacific Northwest Laboratory Engineering Drawings.

FIGURE A-1. Lifting Rate Versus Valve Setting
for Latch Load Cylinders

FIGURE A-2. Latch Load Versus Hydraulic Cylinder Pressure for Latch Test Stand

FIGURE A-3. Latch Rod Force Versus Air Pressure
for Latch Test Stand

FIGURE A-4. Load Cylinder Output Force Versus Pressure for Rod End of 1 1/2 in. Bore, 1/2 in. Rod Hydraulic Cylinder

APPENDIX B
TEST RESULTS

FIGURE B-1. Latch Rod Holding Force
Versus Latch Load,
632 Cycles

FIGURE B-2. Latch Rod Holding Force Versus Latch Load, 1019 Cycles

FIGURE B-3. Latch Rod Holding Force Versus Latch Load (After 1651 Cycles Cam Stroke Reduced to 0.711)

FIGURE B-4. Latch Rod Holding Force Versus Latch Load, 2176 Cycles

FIGURE B-5. Latch Rod Holding Force Versus Latch Load, 3181 Cycles Before Disassembly

FIGURE B-6. Latch Rod Holding Force Versus Latch Load

Neg 0690028-7

FIGURE B-7. Close-up of Wear Pattern on Spool
Contacting Surface of Latch Fingers

Neg 0690028-2

FIGURE B-8. Wear Pattern on Cam Contacting Surface
of Latch Fingers

632 CYCLES

Neg 0690028-5

FIGURE B-9. Spool-Spool Bolt combination

Neg 0690028-3

FIGURE B-10. Wear Pattern on Mating Spherical Surfaces of Spool Bolt and Spool

Neg 0690028-6

FIGURE B-11. Wear Pattern on Finger Contacting
Surface of Latch Spool

Neg 0690343-3

FIGURE B-12. Wear Pattern on Spool Contacting
Surface of Latch Fingers

Neg 0690343-4

FIGURE B-13. Wear Pattern on Cam Contacting
Surface of Latch Fingers

Neg 0690343-6

FIGURE B-14. Wear Pattern on Finger Contacting
Surface of Cam

Neg 0690549-2

FIGURE B-15. Wear Pattern on Spool Contacting
Surface of Latch Fingers

Neg 0690549-3

FIGURE B-16. Wear Pattern on Cam Contacting
Surface of Latch Fingers

Neg 0690549-1

FIGURE B-17. Wear Pattern on Finger Contacting
Surface of Cam

Neg 0690931-2

FIGURE B-18. Wear Pattern on Spool Contacting
Surface of Latch Fingers

Neg 0690931-1

FIGURE B-19. Wear Pattern on Cam Contacting
Surface of Latch Fingers

ELECTROMAGNET CALCULATIONS

Magnetizing Force (B) Required for Holding Force (F)

$$B = \sqrt{\frac{F}{KA}}$$

$$K = \frac{1}{7.213 \times 10^7} \left(\frac{\text{lb-in.}}{\text{line}^2} \right)$$

$$A = 7.7 \text{ in.}^2$$

$$B = \sqrt{\frac{7.213 \times 10^7}{7.7}} \sqrt{F}$$

$$B = 3120\sqrt{F} \text{ lines/in.}^2$$

$$= 438\sqrt{F} \text{ lines/cm}^2$$

$$= 0.483\sqrt{F} \text{ K-Gauss}$$

<u>F, lb</u>	<u>$\sqrt{F}$</u>	<u>$0.483\sqrt{F}$, K-Gauss*</u>
0	0	0
100	10	4.83
200	14.13	6.83
300	17.32	8.37
400	20	9.66
500	22.35	10.8
600	24.5	11.83
700	26.45	12.77
800	28.3	13.7
900	30	14.5
1000	31.6	15.3
1100	33.2	16.0
1200	34.6	16.7

* Plotted in Figure B-20.

FIGURE B-20 Required Flux Intensity (B) Versus Magnet Holding Force (F)

THEORETICAL CURRENT (I) REQUIRED FOR A GIVEN HOLDING FORCE (F)Zero Shim Case

$$NI = H_i l_i + 2(0.313 B_l)$$

$$l_i = 11.2 \text{ in.}$$

$$l = 0$$

$$NI = H_i l_i$$

$$= H_i (11.2 \text{ in.}) (2.54 \text{ cm/in.}) (0.79 \text{ A-turn/cm/Oersted})$$

$$= 22.1 H_i \text{ A-turns}$$

$$N = 644 \text{ turns}$$

$$I = \frac{22.1 H_i}{644} = 0.0343 H_i \text{ A}$$

<u>F, lb</u>	<u>B, K-Gauss</u>	<u>H,* Oersteds</u>	<u>I, A</u>
0	0	0	0
100	4.83	1.85	0.0635
200	6.83	2.0	0.0687
300	8.37	2.35	0.087
400	9.66	2.8	0.096
500	10.8	3.2	0.11
600	11.83	3.9	0.134
700	12.77	4.0	0.1375
800	13.7	5.5	0.188
900	14.5	7.0	0.241
1000	15.3	8.2	0.281
1100	16.0	16	0.548
1200	16.7	25	0.860

* *Reference 4 (Figure 3).*

0.001 in. Shim Case

$$NI = H_i l_i + 2(0.313 B l)$$

$$l_i = 11.2 \text{ in.}$$

$$l = 0.001 \text{ in.}$$

$$NI = 22.1 H_i + 2[(0.313 B)(0.001)] \text{ K-Gauss-in.-6.452 lines per in.}^2/\text{Gauss}$$

$$= 22.1 H_i + 0.00397 B$$

$$N = 644 \text{ turns}$$

$$I = \frac{22.1 H_i}{644} + \frac{0.00397 B}{644}$$

$$= 0.0343 H_i + 0.00618 B A$$

F, lb	B, K-Gauss	(a)	(b)	(a) + (b), A
		0.0343 H_i ,* A	0.00618 B, A	
0	0	0	0	0
100	4.83	0.0635	0.0299	0.0934
200	6.83	0.0687	0.0422	0.1109
300	8.37	0.087	0.0577	0.145
400	9.66	0.096	0.0597	0.156
500	10.8	0.11	0.0668	0.177
600	11.83	0.134	0.0732	0.207
700	12.77	0.1375	0.079	0.217
800	13.7	0.188	0.0848	0.273
900	14.5	0.241	0.0897	0.331
1000	15.3	0.281	0.0947	0.376
1100	16.0	0.548	0.099	0.647
1200	16.7	0.860	0.106	0.966

* From 0.000 in. Shim Case.

0.002 in. Shim Case

$$NI = H_i l_i + 2(0.313 B l)$$

$$l_i = 11.2 \text{ in.}$$

$$l = 0.002 \text{ in.}$$

$$NI = 22.1 H_i + 2[(0.313 B)(0.002)] \text{ K-Gauss-in.-6.452 lines per in.}^2/\text{Gauss}$$

$$= 22.1 H_i + 0.00808 B \text{ A-turns}$$

$$N = 644 \text{ turns}$$

$$I = \frac{22.1}{644} H_i + \frac{0.00808}{644} B$$

$$= 0.0343 H_i + 0.001232 B \text{ A}$$

F, lb	(a)	(b)	(a) + (b), A
	$0.0343 H_i, *$ A	$0.001232 B,$ A	
0	0	0	0
100	0.0635	0.0598	0.124
200	0.0687	0.0844	0.153
300	0.087	0.1154	0.202
400	0.096	0.1194	0.215
500	0.11	0.1336	0.244
600	0.134	0.1464	0.280
700	0.1375	0.158	0.296
800	0.188	0.1696	0.358
900	0.241	0.1794	0.420
1000	0.281	0.1894	0.470
1100	0.548	0.198	0.746
1200	0.860	0.212	1.07

* From 0.000 in. Shim Case.

PACKING FACTOR CALCULATION

$$l_w = \frac{R}{r} \text{ (Length of wire in coil)}$$

$$r = 0.0136 \text{ } \Omega/\text{ft} \text{ (REA CEROC 20 GA. B\&S)}$$

$$R = 5.76 \text{ ohms (Resistance of coil)}$$

$$l_w = \frac{5.76}{0.0136}$$

$$= 423 \text{ ft}$$

$$l_w = \frac{V_w}{A_{wi}}$$

$$A_{wi} = \frac{\pi D_o^2}{4} \text{ (Cross-sectional area of individual wire in coil)}$$

$$D_o = 0.0338 \text{ in. (Diameter of individual wire)}$$

$$V_w = l_w A_{wi} \text{ (Volume of wire)}$$

$$= (423 \text{ ft})(12 \text{ in./ft}) \frac{\pi (0.0338)^2}{4}$$

$$= 4.56 \text{ in.}^3$$

$$V_w = fV_c$$

$$V_c = 6.5 \text{ in.}^3 \text{ (Volume occupied by coil)}$$

$$f = \frac{V_w}{V_c} = \frac{4.56}{6.5} = 0.70 \text{ (Packing factor)}$$

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