FHR 3258
10 May 1966

Final Report

Development of Magnetic Coils for Continuous Use and a Coil-Positioning and Transporter Dolly

Contract No. NAS 8-11735

F. J. Hoppe

Period - June 1964 to February 1966

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama 35812

FAIRCHILD HILLER

Republic Aviation Division
Farmingdale, New York

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

TABLES

ABSTRACT

Water-cooled magnetic coils for capactive discharge service of various diameters have now been developed. These are capable of continuous operation at 15,000-joule energy levels and at the repetition rate of one discharge every 10 seconds.

A mobile coil positioning dolly has also been designed and manufactured.

FOREWORD

This document is the final report covering the work performed under Contract NAS8-11735, control number CPB 04-47591-64 and DCN 1-4-30-01040S1 (1F) from June 1964 to February 1966. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the National Aeronautics and Space Administration.

This contract with Fairchild Hiller, Republic Aviation Division, Farmingdale, New York, was initiated by the National Aeronautics and Space Administration, Manufacturing Engineering Division, George C. Marshall Space Flight Center, Huntsville, Alabama. It was administered by the Contracts Branch, Procurement and Contracts Office, George C. Marshall Space Flight Center. The program was coordinated by: R. Schwinghamer, E. Foster, and J. D. Benight.

Mr. F. Hoppe and J. Christiana were project engineers. Mr. F. Hoppe prepared the final report. B. Leftheris provided technical assistance in the overall design. Mr. Gunther Pfanner was responsible for the overall supervision of the program.

SECTION 1

INTRODUCTION

The "Development of Magnetic Coils for Continuous Use and a Coil Transporter Dolly" program was initiated by NASA under Contract No. NAS-8-11735. The objectives of the program was to conduct a study of magnetic coil configurations and then, based on the study, develop and manufacture four coils (sizes 4, 6, 9, and 12-inch diameters) for continuous operation at 20,000 joules firing at 10 second intervals. A transportable motorized coil positioning device was designed and manufactured.

The program was accomplished in two phases:

Phase I - Magnetic Coil Study, Development and Manufacture

Phase II - Transporter Dolly Design and Manufacture

SECTION 2

MAGNETIC COILS

A. GENERAL

Phase I of this project was conducted to develop and manufacture magnetic coils which can be used in continuous operation for contour corrective forming.

The heat-up rate of the coils at various discharge frequencies and anticipated usage repetition rates was determined, and a coil cooling technique was developed for continuous coil operation with energy discharges of 20,000 joules at 10-second intervals. Four coils were designed and fabricated with diameters of 4, 6, 9, and 12 inches.

B. COIL DESIGN CONSIDERATIONS

In general, failures of water cooled coils have been associated with:

1) Insulation breakdown between turns

2) Mechanical breakdown of the coil winding by necking and stretching

3) Separation of the coil core from the inner windings

4) Separation of the water or high voltage leads from the coil terminations due to bending or necking caused by the rapid movement of the coil during discharge

1. Insulation Failure

Insulation breakdown after two 2KV(1920 joule) uncoupled discharges was experienced with a 10-turn, 4-inch diameter coil manufactured from flattened 1/4" OD x 0.030" wall copper tubing. Insulation of the coil was obtained by interleaving the turns with "Prepreg" (epoxy impregnated glass cloth) without any insulation on the tubing. This type of failure was avoided in subsequent coil design by wrapping "Prepreg" tape about the tubing as it is being wound in addition to interleaving with "Prepreg" strips. Coils have been tested up to 17 KV with this design without insulation breakdown.

2. Mechanical Breakdown

Failure due to necking and stretching of the copper tubing in the first inner turn was experienced with a 4-inch diameter coil similar to the coil described above. Failure occurred after two 5KV (12,000 joule) discharges and resulted from tensile forces exceeding the yield strength of the copper. This problem area was resolved by fitting the copper turing over stainless steel tubing to obtain additional tensile strength.

3. Separation of Coil Core

The third mode of failure, fracture, or separation of the core was overcome by rigidly supporting the core and coil with a micarta back-up plate of sufficient thickness to avoid bending stresses in the coil.

4. Water and High-Voltage Connections

Failure at the joint between the water hose connection and the coil lead was a problem unique to water-cooled coils. The relatively large mass of the external water hoses attached to the coil leads increased the forces applied to the leads during the discharge cycle and resulted in detachment of the water hoses or the bending of the coil tube leads. Repeated discharges fatigued these connections and ultimately caused failure of the joint. This problem was resolved by combining both the water and high voltage connection into one lightweight connection. A special wide flange steel end fitting was manufactured and silver soldered to the ends of the coil to prevent the bending of the tube leads. A commercially available heli-arc-type water cooled power cable is used to connect the coil to the capacitor discharge bank and to the water supply. It was found best to make the center terminal of the coil at ground potential and the water outlet.

C. COIL CONSTRUCTION

The 4-, 6-, 9-, and 12-inch diameter coils are identified as MR & T-SK 879, 880, 881, and 882, respectively, and are shown in Figures 1 through 4.

The steps involved in manufacturing the 12-inch coil are itemized below. The procedure for the other three sizes is identical with the exception of certain items such as tubing length and number of turns which are delineated in Figures 1 through 4.

1) Insert seven feet of stainless steel tubing 3/16" OD x 0.015" wall into a fifty-foot length of copper tubing 1/4" OD x 0.030" wall so that the combined tubing will make up the first seven inside turns of the coil.

2) Flatten tubing to 0.140 inch width leaving 6 inches on each and unflattened.

3) Bend a 2-inch length 90° each end of the tubing for connector attachment (note: outside bend should be fabricated at end of coil wrapping operation).

4) The first inner turn of the coil was formed using a modified tube bending tool to prevent the buckling of the tubing. The bending die was split to form two parallel discs which could be taken apart to remove the coil after making the 360° bend (see Figure 5).

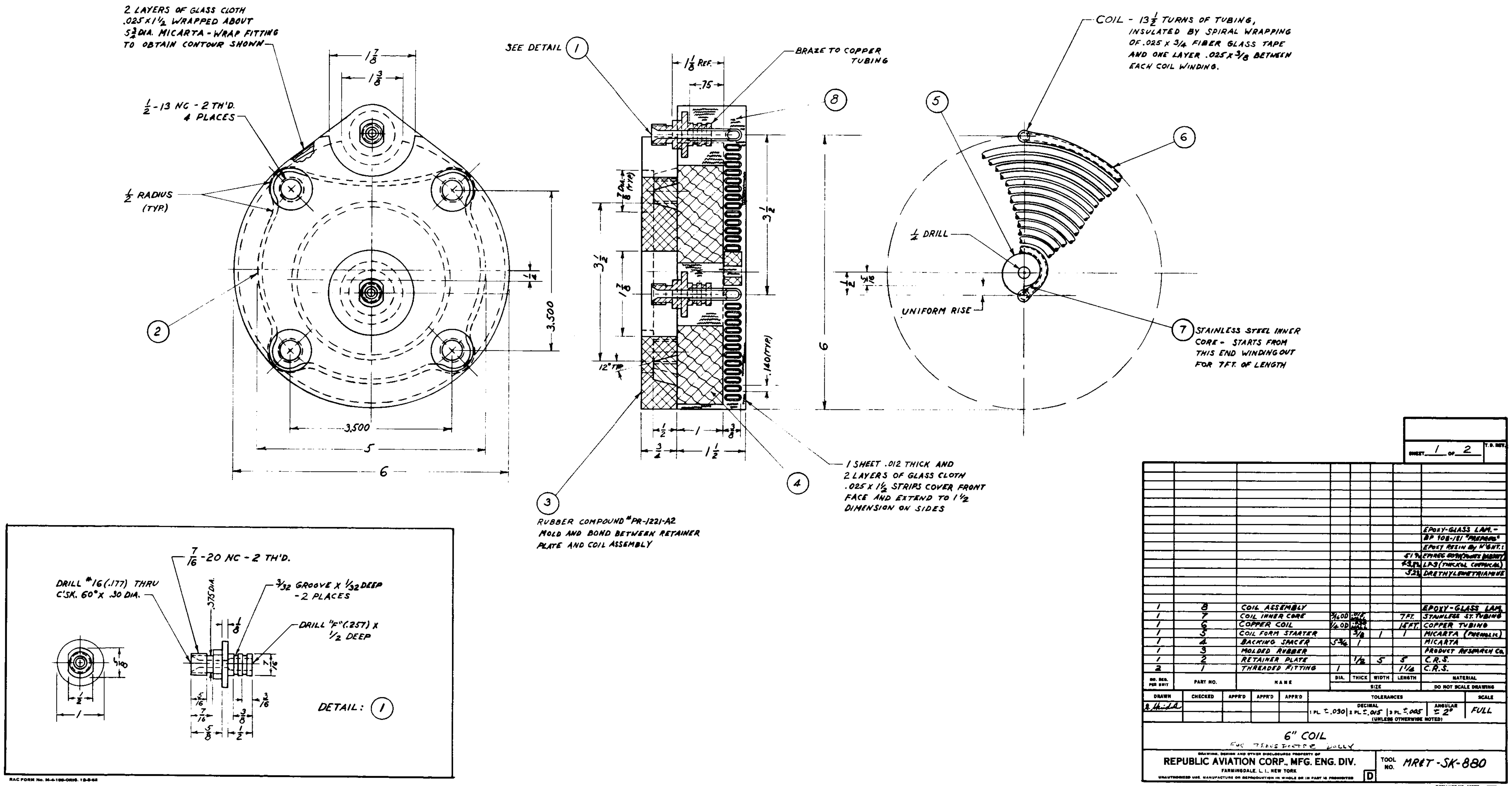
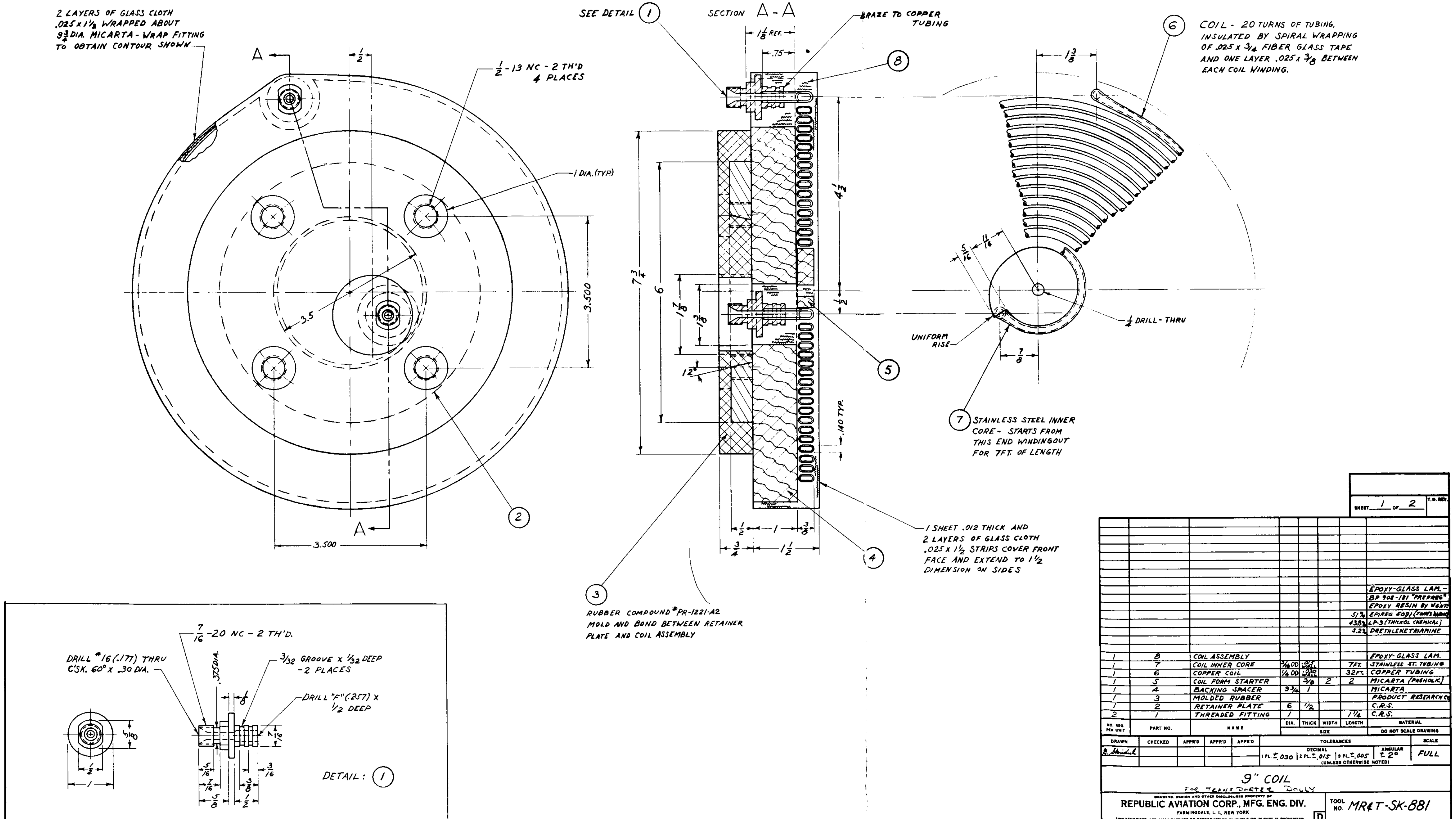


Figure 2. Six-Inch Coil



NO. REQ. PER UNIT	PART NO.	NAME	DIA.	THICK	WIDTH	LENGTH	MATERIAL
							EPOXY-GLASS LAM.-
							BP 908-181 "PREPREG"
							EPOXY RESIN BY WGHT.
						51%	EPIREG 5091 (TOWNS [illegible])
						43.8%	LP-3 (THIKOL CHEMICAL)
						5.2%	DRETHLENETRIAMINE
1	8	COIL ASSEMBLY					EPOXY-GLASS LAM.
1	7	COIL INNER CORE	3/16 OD	.015 WALL		7FT.	STAINLESS ST. TUBING
1	6	COPPER COIL	¼ OD	.032 WALL		32FT.	COPPER TUBING
1	5	COIL FORM STARTER		3/8	2	2	MICARTA (PHENOLIC)
1	4	BACKING SPACER	9¾	1			MICARTA
1	3	MOLDED RUBBER					PRODUCT RESEARCH CO.
1	2	RETAINER PLATE	6	½			C.R.S.
2	1	THREADED FITTING	1			1¼	C.R.S.

Figure 3. Nine-Inch Coil

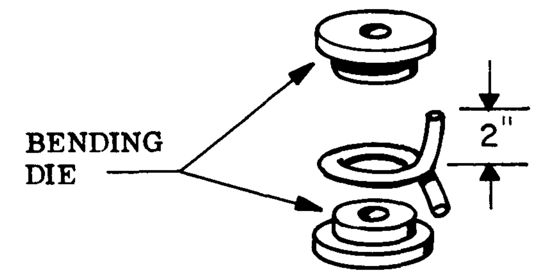


Figure 5. First Inner Turn of Coil

5) Wrap 27 turns of tubing, taping tubing with BP 908-181 epoxy impregnated glass cloth strip. Spiral wrap tape, overlapping the previous wrap as the coil is wound into place. In addition, place a single layer of the impregnated tape between each succeeding winding of the coil.

6) Insert phenolic shaped plug in the center opening of the coil. Clamp this assembly between two pressure plates faced with mylar, to prevent bonding of the coil to the plates, and oven cure at 325°F for 90 minutes. Be sure to clamp the outer turn of the coil to prevent uncoiling during the heat curing operation.

7) Trim tube ends and silver solder end connections. Clean and check for water tight connection.

8) The following steps complete the assembly of the coil to the 1" thick phenolic backing plate:

   a) Prepare 1 ply of fiberglass cloth for the face of the coil, slitting it so that the cloth will come up the sides of the coil for approximately 2 inches. Also prepare enough 1-1/2 inch wide fiberglass webbing strips to provide two additional fiberglass facings.

   b) Prepare the epoxy resin

51% (by weight)	Epirez 5091 (Jones Dabney Co.)
43%	8% LP-3 (Thiokol Chemical)
5%	2% Diethylenetriamine

   Pour and spread the resin over the roughened coil face. Lay the single layer of fiberglass over the coil face and wipe in place. Spread more resin and lay the 1-1/2 inch strips over the coil face and wipe in place. Pour more resin and lay 1-1/2-inch strips 90° to those previously positioned. Lay a wax aluminum plate over this assembly and turn the assembly

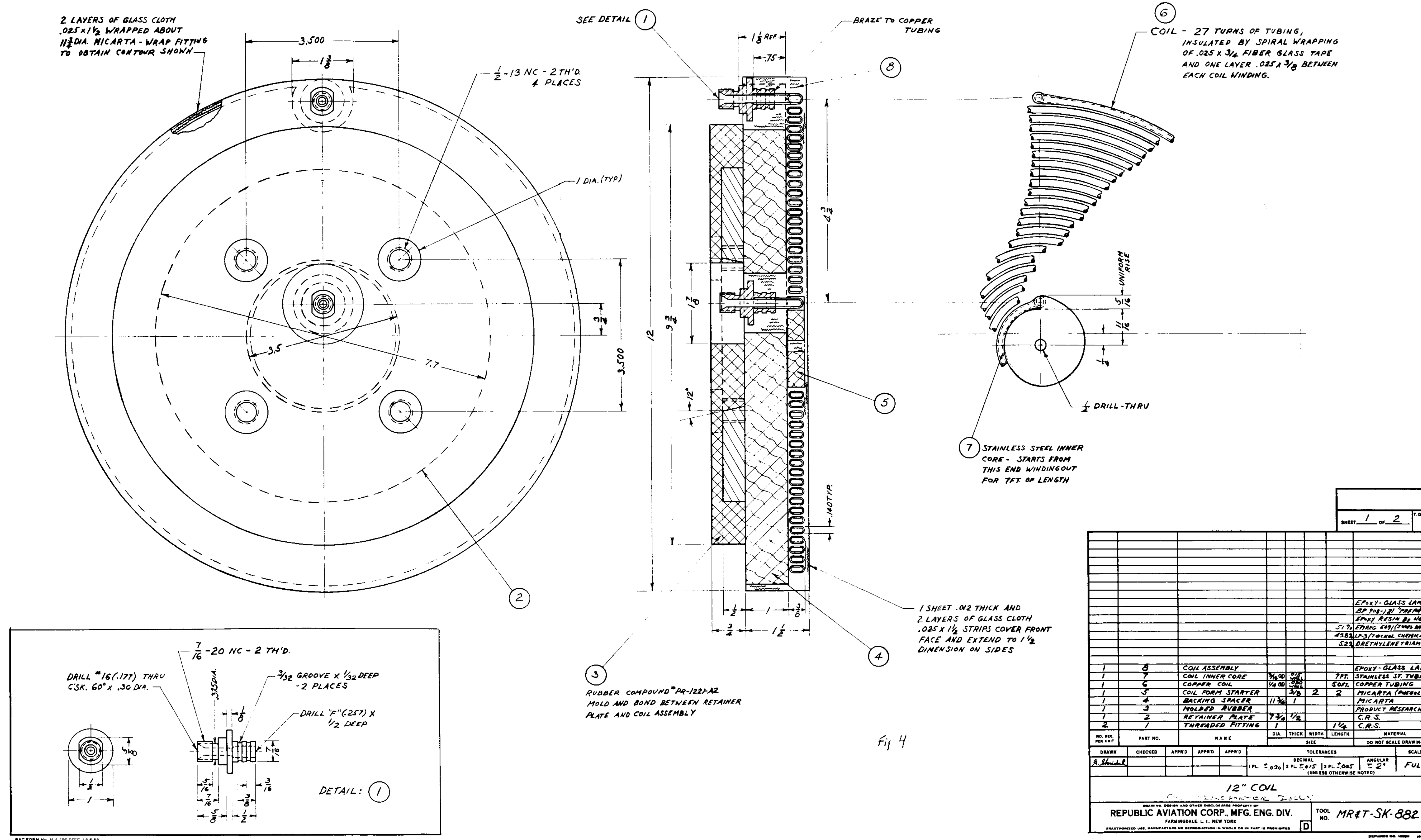


Figure 4. Twelve-Inch Coil

7-1

7-2

over. Spread resin over the roughened back of the coil. Place the roughened phenolic backing plate over the coil and clamp the coil, aluminum plate, and the phenolic backing plate together. Work all the facing material up the sides adding resin as required. Wrap the sides with two layers of the 1-1/2-inch wide webbing strip material. Clamp together with a waxed aluminum strap. Room temperature cure the assembly over night.

9) Roughen the back surface of the phenolic backing plate. Make a waxed sheet metal dam 5/8-inch high and approximately 3/4-inch bigger than the steel adaptor plate. Pour some prepared rubber sealing compound No. PR-1221-A2 (Product Research Co.) in the cavity. Place the steel adaptor plate in position. Complete pouring sealing compound to cover the adaptor plate and to the top of the 3/4-inch high dam. Also dam the area around the mounting bolts as shown in the drawing, Figure 4. Room temperature cure over night. This completes the assembly of the coil. Allow at least two days for curing of the rubber before using the coil at high energy levels.

D. PRELIMINARY COIL HEAT-UP AND COOLING TESTS

Preliminary tests were made prior to the finalized coil design to determine the extent of coil heat-up and the degree of cooling obtained with several coolant mediums. These tests are included in this report.

1. Calculated Temperature Rise

The 4" coil configuration was selected for preliminary heat-up tests since the most severe heat-up problem will occur with a 4" rather than a 12" coil. In the latter the heat is distributed into a greater volume, and a greater surface area is exposed to cooling between discharges.

The minimum target requirements of energy discharged through the coil were 20,000 joule discharges applied continuously at 10-second intervals. Coil cooling experiments were conducted to compare gas and water as coil coolants. Rather than begin with actual capacitor discharges through a coil, it was considered advisable to begin by passing steady state (AC) current with continuous coil input power up to the equivalent 2,000 watts.

A 120" length of 0.19" ID x 0.26" OD copper tubing was flattened to the cross section shown in Figure 6 and wound into a 10-turn coil with fiberglass insulation between turns.

The conductor cross section was 0.0277 square inch; with a 120" length, the coil resistance calculates as 0.0032 ohm. The measured resistance was 0.0038 ohm.

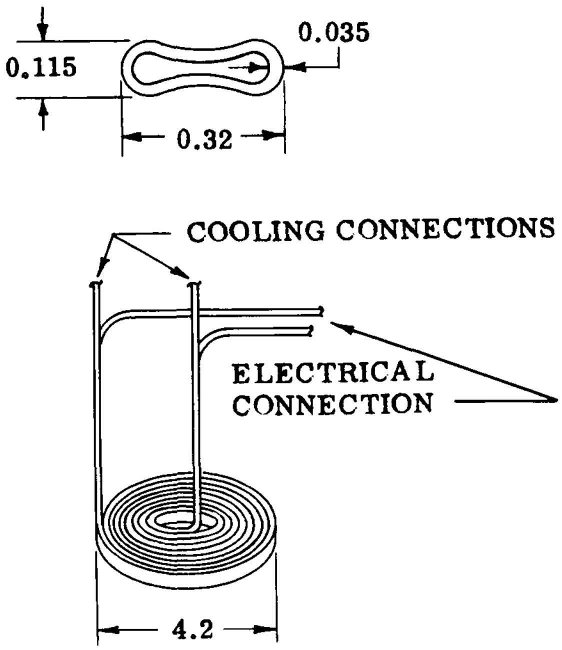


Figure 6. Test Coil

A 20,000-joule discharge every 10 seconds averages to a power of 2,000 watts. Therefore, based on the 0.0038 ohm resistance value, the equivalent steady state current which provides this power is:

$$i^2 = \frac{2,000}{0.0038}$$

$$i = 725 \text{ amperes}$$

A series of tests in which current values up to 800 amperes were passed through the coil is discussed below.

Since the steady state test only simulates an average temperature and since the coil temperature will actually be higher immediately after the discharge, it is important from the viewpoint of the temperature resistance of the coil matrix material (epoxy) to calculate the coil interior temperature immediately after discharge.

To obtain a conservative calculation of coil heat-up per discharge, assume that all the energy in a 20,000-joule discharge is lost in heating the coil. The calculation for a 0.1 cal/gm/°C specific heat for copper follows:

Copper Volume = 0.0277 (120) = 3.32 cubic inches = 54.3 cc

Copper Weight = 54.3 (8.89) = 484 gms

Energy In = 20,000 joules = 4,780

$$\frac{\text{Energy}}{\text{Weight}} = \frac{4,780}{484} = 9.89 \text{ cal/gm}$$

$$\text{Temp. Rise} = \frac{9.89}{0.1} = 98.9°\text{C} = 210.1°\text{F}$$

The above calculation is based upon uniform current density in the copper to produce a uniform temperature rise. Actually, the current density will be higher at the outer surface of the conductor. However, for a 5 KC discharge frequency the skin depth of copper is 0.094" which is greater than the 0.035" conductor thickness.

Consequently, as the plot (Figure 7) of current density squared vs distance in the conductor shows, the energy loss density decreases only in a 1:0.475 ratio through the conductor thickness. The calculated 210.1°F temperature rise can be taken as the mean of the energy loss density so that the temperature increase at the outer surface would be about 300°F.

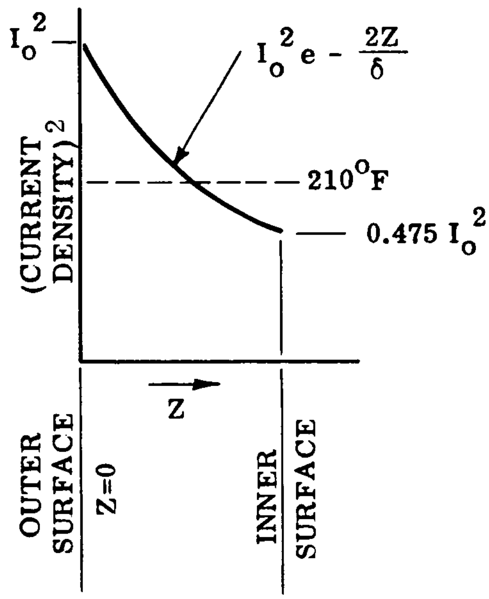


Figure 7. Current Density vs Conductor Distance

Since the temperature calculation was based on dissipating all discharge energy as heat loss in the coil and since energy is actually also lost as workpiece heat, workpiece deformation, and circuit heat, it seems reasonable to assume a maximum instantaneous temperature rise at the outer conductor surface of only 200°F rather than 300°F. Assuming that temperature prior to discharge is 120°F due to cooling, the maximum outer conductor surface temperature would then be 270°F. Since the useful maximum temperature of BP-908 epoxy which contacts the conductor surface is 400°F, temperature considerations per se would not create a problem.

2. Steady-State Coil Heating Tests

The 4.2" tubular coil was heated with alternating current which was adjusted to the desired current value by a variac control as shown in Figure 8. As the coil temperature increased, the input voltage was adjusted to maintain a constant current. Cooling was obtained by air at 80 psi, nitrogen at 125 psi and water at 0.3 gallon per minute. The temperature of the cooling water was measured by a thermometer in the coolant stream after passage through the coil. The temperature of the coil was measured by a thermocouple located in the insulator between coil turns. The coil exterior was well insulated to limit heat absorption to the coolant only.

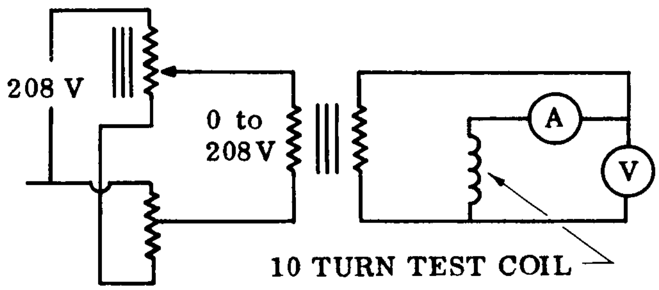


Figure 8. Test Setup

The results tabulated in Table 1 show that for a limiting coil temperature of 400°F, gases can be considered as the coil coolant only when the average power is less than 600 watts. (See Figure 9 which plots estimated power based on resistivity correction with some scatter due to non-equilibrium conditions.) By contrast, tap water proved to be a very effective coolant, and at the maximum power of 2,400 watts (800 amps) the water temperature increase was only 65°F. This is reasonable agreement with a temperature rise of 55°F calculated from specific heat and a 0.3 gallon per minute water flow.

3. Capacitor Discharge Coil Heating Tests

Since a 20,000-joule discharge is the energy level at which glass laminate spalling has been observed to occur with 4-inch coils, it was decided to conduct the majority of the cooling experiments without a work-piece coupled to the coil. Under these conditions mechanical forces within the coil are minor, and from the aspect of coil cooling the experiment is more stringent since energy is not expended in forming work or workpiece heating. The fact that the discharge period is extended is inconsequential since the duration is still too short to affect temperature losses to surroundings.

TABLE 1. 10 TURN, 1.5" ID, 4.2" OD, STEADY STATE COIL HEATING TEST

							Input Voltage, Coil Temperature, /Coolant Temperature °F at Time after Start of Heating							
Test	Amps	Initial Voltage	Coolant Temp. In. °F	Coolant Temp. Out °F		Cooling	1 Min. Volts	Temp	2 Min. Volts	Temp	3 Min. Volts	Temp	5 Min. Volts	Temp
1	150	0.70	73	-	Air	80 psi	0.75	130	0.75	143	0.75	145	0.76	147
2	250	1.20	73	-	Air	80 psi	1.36	253	1.46	309	1.47	332	1.50	352
3	350	1.77	73	-	Air	80 psi	2.49	379	2.95	475	3.2	563		
5	250	1.25	62	-	Nitrogen	125 psi	1.37	160	1.37	173	1.39	175	1.39	176
6	350	1.77	62	-	Nitrogen	125 psi	2.20	291	2.31	341	2.37	368	2.37	371
7	150	0.75	59	61	Water	0.3 gpm	0.79	62/61	0.79	62/61	0.79	62/61	0.79	62/61
8	250	1.30	59	65-66	Water	0.3 gpm	1.31	64/65	1.31	64/65.5	1.31	64/65.5	1.32	64/65.5
9	350	1.80	59	70-72	Water	0.3 gpm	1.80	67/70	1.81	67/71	1.81	67/71.5	1.82	67/71.5
10	500	2.66	59	81-85	Water	0.3 gpm	2.67	73/81	2.7	76/83.5	2.7	76/84	2.75	76/85
11	650	3.65	59	97-104	Water	0.3 gpm	3.65	84/97	3.78	86/103	3.8	86/104	3.80	86/104
12	800	4.40	59	118-124	Water	0.3 gpm	4.45	112/118	4.45	144/122	4.50	114/123	4.5	114/124

To estimate power, use r = 0.0038 ohm at room temperature and correct for resistivity change with observed coil temperature.

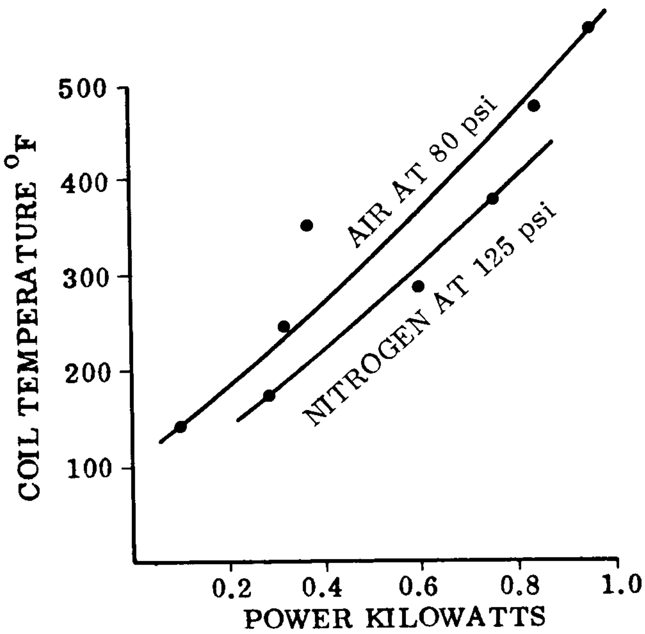


Figure 9. Power vs Coil Temperature

Tests began with the 960-uf capacitor bank. Discharges of 6. 5 kilovolts (20, 000 joules) were employed at intervals of about 7 seconds. A total of 10 discharges were made through the coil during a period of 70 seconds and during this time 1500 cc of tap water coolant was collected. A thermocouple at the exit end of the coil connected to a laboratory galvanometer gave an indication of a temperature rise of the coolant for about two seconds. This cooling time is of more interest than the observed temperature since the galvanometer could not respond rapidly enough to give an instantaneous temperature reading. Suprisingly, in view of the steady state tests and calculations which predict a 55°F temperature rise for an average 2, 000 watts, the temperature of the cooling water rose only 7°. For 1500 cc, this temperature rise is an energy change of only 24, 400 joules. Since the 10 discharges contained 200, 000 joules, only 12. 2% of the discharge energy was dissipated in the work coil in these experiments.

This rather suprising result was confirmed by several repeat experiments, permitting only the conclusion that high contact resistances existed elsewhere or that switch losses were very high for this relatively low energy, long current duration operation of the 155, 000 joule bank.

A workpiece was now coupled and clamped to the coil under a 20, 000-joule discharge. The water temperature rise was not measured but, expectedly, the galvanometer movement was about 1/2 of the uncoupled experiments due to workpiece deformation and heating.

In addition to the suprisingly low temperature rise obtained in dynamic heating experiments, the preliminary static and dynamic heating tests served the useful purpose of demonstrating that internal cooling with tap water is practical and effective.

E. FINAL HEAT-UP AND COOLING TESTS

Heat-up and cooling tests were conducted with the 4-inch diameter coil, with the 30 MFD and the 960 MFD capacitor tanks at various energy levels (see Table 2). Even with water flow rates as low as 0.132 gallon per minute (coils under normal working conditions have a flow rate of 0.3 gallon per minute), the temperature rise was only 2°F.

Additional tests were conducted using the same test procedures as before but with the 240 MFD Bank firing at various time intervals (see Table 3).

It was noted that reducing the firing rate by two also reduced the temperature rise of the coil cooling water by two. A slightly higher temperature rise was noted even at very low energies when the coil was discharged without being coupled to a workpiece. A reduced rate of firing appears to have more effect on reducing the coil cooling water temperature rise than any of the other factors.

When firing at one shot every 10 seconds with the 240 MFD bank during experiment No. 1, the electrical leads attached to the copper tubing of the coil became hot enough to melt the plastic insulation and short to ground, even though the coil cooling water temperature only increased 10°F. In addition to this problem, the rubber block mounting method to adapt the coil to the damper portion of the transport dolly was failing at the higher energy levels (Figure 10).

At this point, the coils were redesigned and water cooled power cables were incorporated with a new coil mounting system adapted (Figure 11). A lightweight water-cooled cable was tried first, but this cable was found to snap itself like a whip in any position that was not supported and consequently, to tear itself loose from the end connectors. A heavier gage water-cooled cable (Linde #54Y63) was substituted. This cable was found to perform satisfactorily.

A steel adaptor plate was bonded with a rubber tank sealant compound to the phenolic backing plate of the coil. Steel was used as the adaptor plate to reduce the repulsion force due to the induced voltages during the capacitor discharge. Tests conducted at high energy levels with this method of mounting the coil to the adaptor plate proved satisfactory.

Tests were conducted with the transporter dolly and a 9-inch diameter coil incorporating the water cooled cables and the new mounting system (Figure 12). These tests were conducted using the 240-MFD bank firing at different high-energy levels and at various firing rates to determine and record cooling water temperature use. See Table 4.

TABLE 2. CAPACITOR DISCHARGE COIL HEATING TESTS

Experiment No.	Coupling *	Capacitor Bank uf	Discharge Voltage	Energy Per Shot	No. of Shots	Total Energy for Series	Water Flow Rate Gal/Min	Temp. Increase of Collected Water
1	C	960	2KV	1920J	10	19,200J	0.0063	15.3°F
2	C	960	3KV	4320J	10	43,200J	0.0528	10°F
3	N	30	6.5KV	635J	10	19,050J	0.132	2°F
4	C	30	6.5KV	635J	10	19,050J	0.0528	20°F
5	N	30	6.5KV	635J	10	19,050J	0.0063	53°F
6	C	30	5.0KV	375J	60	11,250J	0.0066	25°F
7	C	30	3KV	135J	60	8,100J	0.0063	25°F

Conditions:

7-Turn, Steel-reinforced, glattened tubing coil (4 in. Dia.); coil coolant volume -0.0063 Gal.

*C = Coupled to 1/2-inch plate supported by rubber

N = No workpiece coupling

TABLE 3. CAPACITOR DISCHARGE RAPID FIRING COIL HEATING TESTS

Experiment No.	Coupling*	Capacitor Bank uf	Discharge Voltage	Energy Per Shot	No. of Shots	Rate of Firing	Water Flow Gal/Min	Temp. Increase of Collected Water
See experiment 2, Table 1	C	960	3KV	4320J	10		0.0528	10°F
1	C	240	6KV	4320J	10	1 Every 10 sec	0.0528	10°F
2	C	240	6KV	4320J	10	1 Every 20 sec	0.0528	4°F
See experiment 4, Table 1	C	30	6.5KV	635J	30		0.0528	20°F
3	C	240	2.3KV	635J	30	1 Every 2 sec	0.0528	4°F
4	N	240	2.3KV	635J	30	1 Every 2 sec	0.0528	5°F
5	C	240	2.3KV	635J	30	1 Every 10 sec	0.0528	2°F

*C = Coupled to 1/2-inch plate supported by rubber

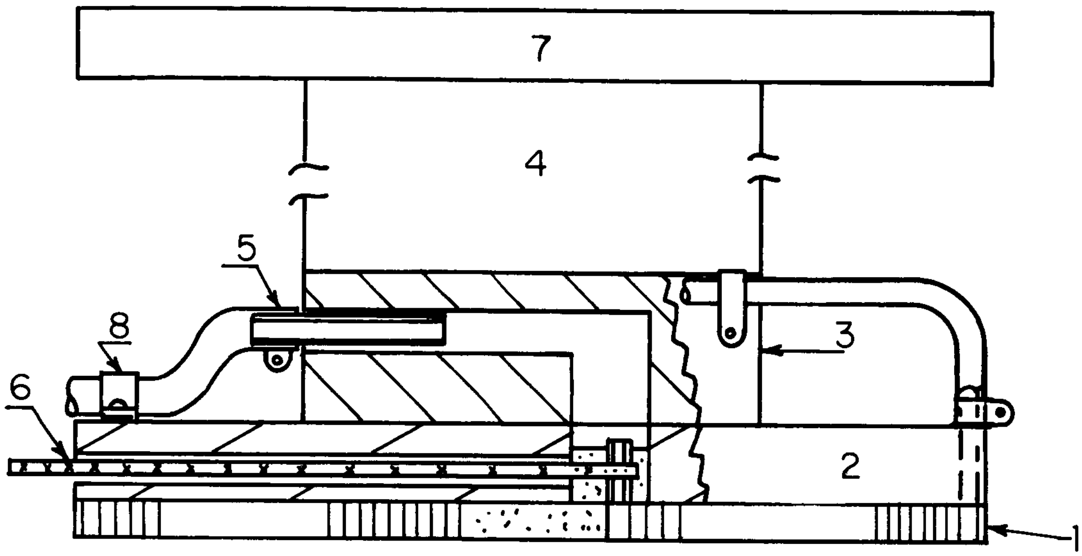
N = No workpiece coupling

TABLE 4. HIGH-ENERGY CAPACITOR DISCHARGE RAPID FIRING COIL HEATING TEST

Experiment No.	Coupling	Capacitor Bank uf	Discharge Voltage	Energy Per Shot	No. of Shots	Rate of Firing	Water Flow Gal/Min	Temp. Increase of Collected Water
1	C	240	8KV	7680J	5			10°F
2	C	240	9KV	9720J	5			7°F
3	C	240	10KV	12,000J	5	1 Every 10 sec.	.145	7°F
4	C	240	11.2KV	15,000J	5			10°F
5	C	240	11.2KV	15,000J	8			13°F
6	C	240	11.2KV	15,000	10			16°F

Conditions:

1. 20-turn-steel-reinforced flattened tubing coil (9 inch diameter)
2. Mounted on transporter dolly - 10 psi damper pressure
3. Coupled to 1 inch aluminum plate clamped to bench



1. Water cooled coil
2. Micarta backup plate
3. Rubber manifold
4. Rubber coil-piston spacer
5. Water hose and connection
6. Braided copper electrical lead
7. Piston
8. Clamp fastener

Figure 10. Rubber-Block-Mounted Coil

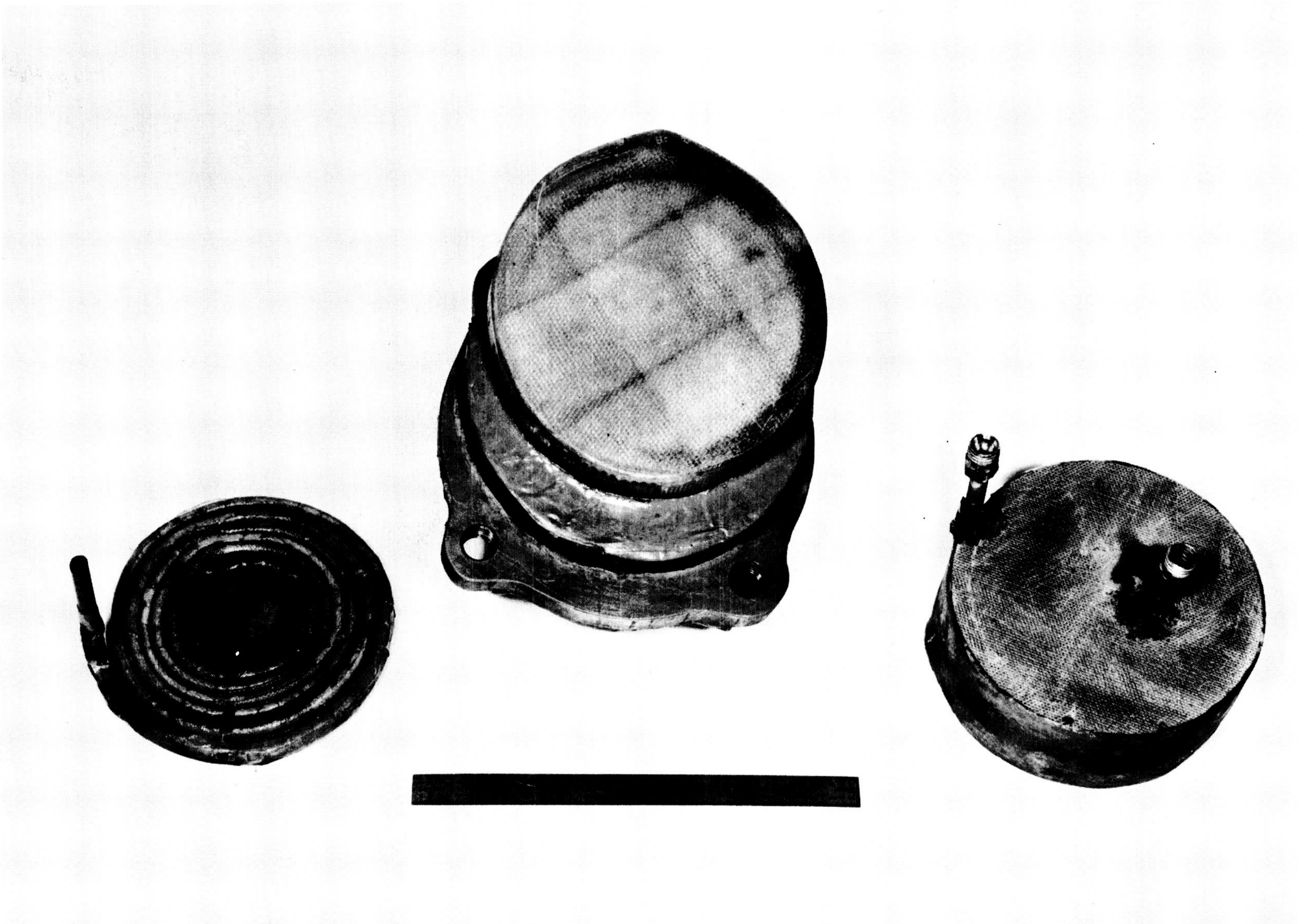


Figure 11. Rubber-Mounted Steel Adapter Plate, Magnetic Coil, and Coil Construction

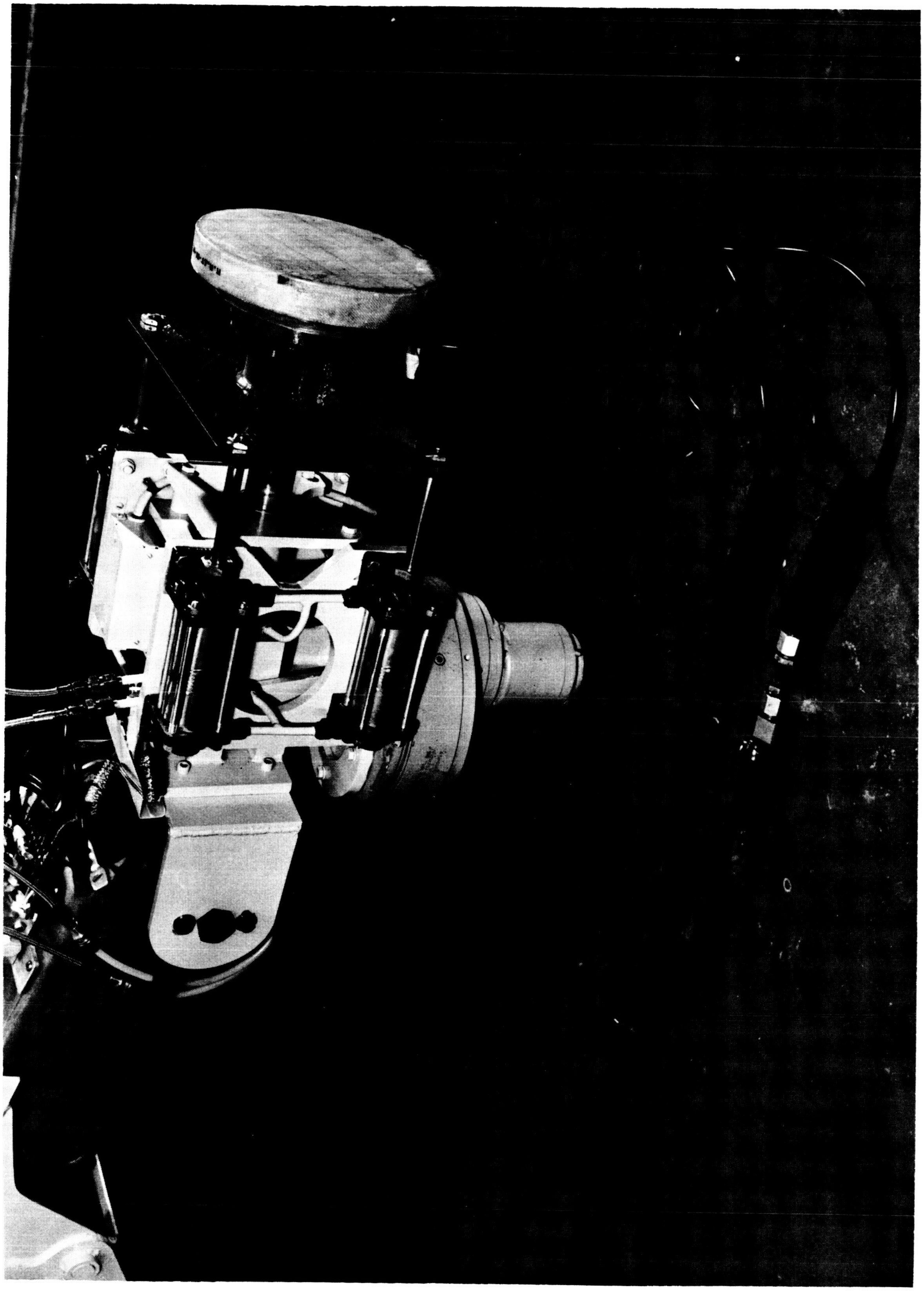


Figure 12. Coil Adaptor Assembly

A maximum temperature rise of 16°F was obtained after firing 10 shots, one every 10 seconds. Additional shots did not increase the water cooling temperature, even though the coil did not have the design water flow rate of .3 gal./minute due to a restriction in the coil winding. A 10°F rise in the coil cooling water is reached very rapidly at almost any energy level when firing at a rapid repetition rate, but then levels off, and any additional temperature rises are minor.

The 9-inch diameter coil high-energy (15,000-joule, 240-MED bank) tests also served to test the complete assembly of the transporter dolly and the coil adaptor. Tests were conducted with the other three sizes of coils at the 15,000-joule, 240-MFD level to check coil structural integrity.

F. WORK OUTPUT VERSUS BANK FREQUENCY

A number of trials were performed with the 4-inch diameter coil to determine work output versus various capacitor bank sizes and frequencies. Refer to Figure 13 and Table 5. As can be seen in Table 5, the efficiency of the 960 MFD bank was considerably less than that of the 30 MFD and 250 MFD capacitor banks.

TABLE 5. WORK OUT PUT VERSUS CAPACITOR BANK SIZE AND FREQUENCY

Capacitor Bank	1/4 Cycle Frequency KC	Discharge Level		Dome Depth Inches	Workpiece Volume Change ml
		KV	Joules		
240 uf	7	3.0	1080	.30	50
30 uf	23	8.5	1082	.33	53
30 uf	23	12.0	2160	.65	158
240 uf	7	4.3	2220	.68	165
960 uf	2.1	3.0	4320	.45	105
240 uf	7	6.0	4320	1.13	250
30 uf	23	17.0	4335	1.08	230
960 uf	2.1	4.3	8880	.80	197
240 uf	7	8.6	8880	1.64	330

The coil and the work piece can be studied as two inductances in parallel as shown in Figure 14. The equivalent inductance is given by:

$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M} = \frac{L_1 L_2 - 0.25 L_1 L_2}{L_1 + L_2 - \sqrt{L_1 L_2}}$$

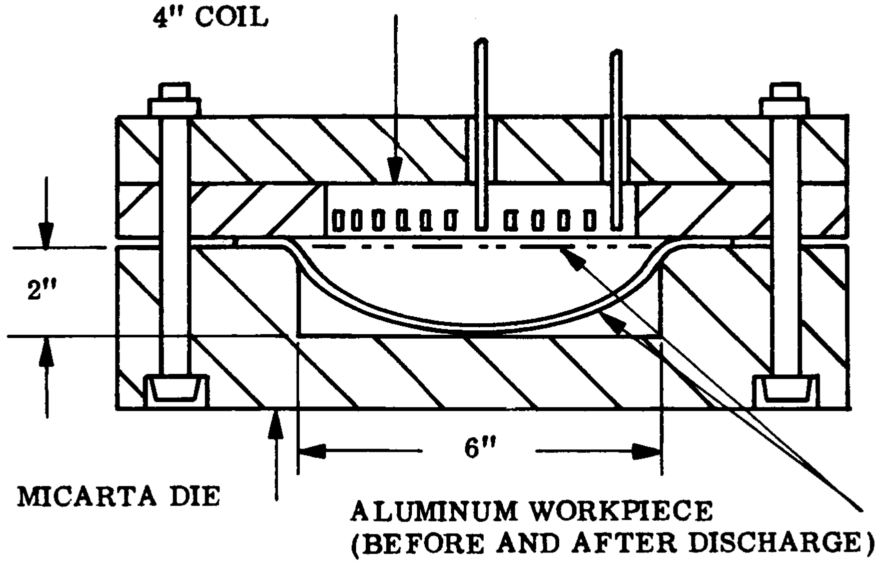


Figure 13. Magnetic Coil Forming Test Setup

Let $M = 0.5 \sqrt{L_1 L_2}$

Coefficient of coupling $= 0.5$

or $$L_{eq} = \frac{0.75\, L_2\, L_1}{L_1 \left(1 - \sqrt{\frac{L_2}{L_1}}\right)} = \frac{0.75\, L_2}{1 - \sqrt{\frac{L_2}{L_1}}}$$

$L_1 = 100\ \mu h$ for a 21-turn coil

$L_2 = 0.02\ \mu h$ of the driver (12-inch coil)

Thus, $\frac{L_2}{L_1} << 1$

hence, the equivalent inductance is given by:

$$L_{eq} = 0.75\, L_2$$

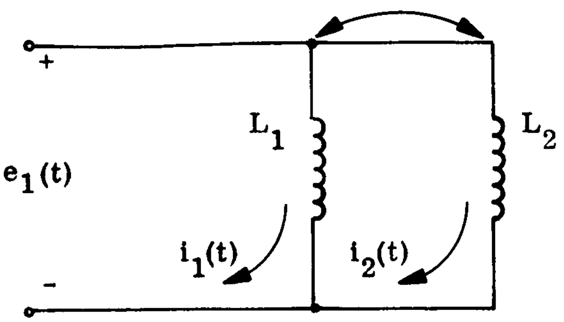


Figure 14. Schematic Representation of Coil/Workpiece Interrelation

This result shows that, as long as the workpiece is coupled to the coil, the inductance of the coil does not affect the results of forming.

L_2 depends on the properties of the metal to be formed (i. e., depth of penetration, diameter of the coil, etc.). It does not vary very much, however, and it stays within the same order of magnitude.

The coefficient of coupling varies during the movement of the metal. The mutual inductance, therefore, varies during forming, and this change causes a change of frequency during forming.

From other work, it has been found that forming takes place during the first one quarter of a cycle. This is shown in the following equation.

$$E = -\frac{\mu I R}{y} v - \mu R \ln \frac{y}{y_o} \cdot \frac{dI}{dt}$$

where

μ = electrical permeability

R = mean radius of the coil

I = instantaneous current

y = distance of work piece from the coil

y_o = initial stand off distance of work piece from the coil

v = instantaneous velocity of work piece

t = time

E = induced voltage in work piece
(repulsion of the metal depends on the magnitude of this voltage)

As long as I and $\frac{dI}{dt}$ are of the same sign, E is large. This is the condition during the first current rise. Since v is always positive, and y changes only a small amount, it can be seen that after the first peak, $\frac{dI}{dt}$ becomes negative and the magnitude of E becomes small. (Since I is still positive)

For a capacitor bank working near the critical damping point, therefore, forming can only be accomplished during the first quarter cycle. This is manifested by the large change of frequency after the first current peak which indicates decoupling between the coil and the work piece.

Thus, during the first quater cycle, the coil inductance and size have a secondary effect on the rate of forming. The primary effect comes from the impedance of the capacitor bank itself.

This is shown in the tests performed with the three different capacitor banks, using the same coil at the same energy levels (see Table 5). The banks with the lowest inductance (240 MFD, at 30 KC and 30 MFD at 25 KC w/o load) did more than twice as much work as the capacitor bank with large inductance (i.e., 960 MFD at 10 KC w/o load).

SECTION 3

RECOIL ASSEMBLY

A. DAMPING OF COIL RECOIL

Two methods for damping the recoil have been evaluated. The first method utilizes compression of the air within a closed end fibre laminate cylinder. A photograph of this assembly is shown in Figure 15. A cross section view showing the details of construction is given in Figure 16. Tests with this assembly have been carried out at energy levels up to 20,000 joules (6.45 kv at 960 uf). It was observed during these tests that the coil recoiled 6-1/2 inches from the workpiece at 20,000 joules and was returned to 2-1/2 inches from the workpiece by the action of the compressed air in the fibre laminate cylinder upon the piston end of the coil assembly.

Although this technique was effective in damping-out recoil, it had several disadvantages for practical use.

1) It would require positive actuation, such as a spring, to insure returning the coil to the workpiece

2) A coil-guiding saddle would be required for each coil size. Using the 12-inch diameter saddle with adaptors for the smaller coils would create a problem in locating the small 4-inch coil against a relatively sharp concave radius since the effective coil diameter would be 12 inches. To alleviate this deficiency would entail providing a piston of longer length to serve as a guide.

3) The bulkiness and weight of the assembly was not compatible with the intent of using the coil as a portable "hammer" mounted on the end of a boom.

All of the above disadvantages were eliminated by the second method which incorporated four commercially available pressurized air cylinders as the damping mechanism and an adaptor plate to mount various diameter coils (Figure 17). This system not only damps the coil recoil, but also provides an in-and-out motion which is utilized for final and positive positioning of the coil face to the workpiece. The cylinders are actuated from the pendant switch through a solenoid operated four-way air valve. The hold-down pressure is adjustable through a pressure regulator valve. A 1/4-inch-thick rubber pad is sandwiched between the coil and adaptor plate to reduce the shock load. This pad also provides a flexible joint to assure maximum coupling of the coil to the workpiece.

B. COIL ADAPTER ASSEMBLY

The coil adaptor assembly (MR&T-SK-878), is designed to 1) mount four different size coils (4-, 6-, 9-and 12-inch diameter - Figure 18), 2) dampen the coil shock load through the four air cylinder cushions (Figure 17) and 3) position the coil both in the vertical and horizontal planes (Figure 19).

The horizontal attitude change is obtained by rotating the assembly about the hinge pin and driving the system with a "Slo Syn" high-torque electric gear-motor. The motor is operated remotely in either direction by actuating a switch on the pendant. Travel is limited at each end of the 45° sweep by safety micro-switches.

The vertical attitude of 100° sweep is controlled by means of the hydraulic leveling cylinders that are actuated by turning the diverter valve to leveling and operating the boom up or down switch. There is only one position (and that is indicated with a pointer on the inside of the boom) that will produce a level position when the boom is traversed up and down. If an angle which will remain constant when the boom is traversed up and down is desired, the coil adapter is leveled to the indicated mark and the bolts on the side clamp bracket are loosened and the unit is positioned to the desired angle and locked. The overall hydraulic system is protected by a holding valve which not only protects the unit in case of power failures but also has a pressure relief valve which releases excessive pressure due to external sources. To provide end travel protection, an addiation shutoff valve was connected at the end of and between the bleed lines (Figure 17). The valve is opened by cam actuation at the end of each travel which bypasses the slave leveling cylinders and removes the hydraulic pressure.

The coil recoil damping is accomplished through the four air cylinders mounted on the sides of the coil adaptor assembly. This system not only provides the damping necessary but also gives a straight in-and-out motion for final positioning of the coil on the work. The system is controlled with a switch on the pendant box through a Versa #WX-4423 four-way double solenoid valve. Pressure is regulated only on the forward, or out, stroke of the cylinders with an adjustable pressure regulating valve mounted on the lower boom assembly. Pressures between 10 and 20 psi have been found to work best.

A 1/4-inch-thick rubber pad is provided between the coil adaptor plate and the face plate to dampen the shock load and also provide a flexible joint to assure that the coil will lay flush on the work surface.

Water-cooled Linde #54Y63 power cables are used to provide a single water and high-voltage connection on each end of the coil. Fittings are provided on the other end of the cables for water connections and for the high-voltage connections to the capacitor bank cables. A water inlet (50 psi) and a drain must be provided.

Figure 15. Compressed Air Recoil Damping Assembly

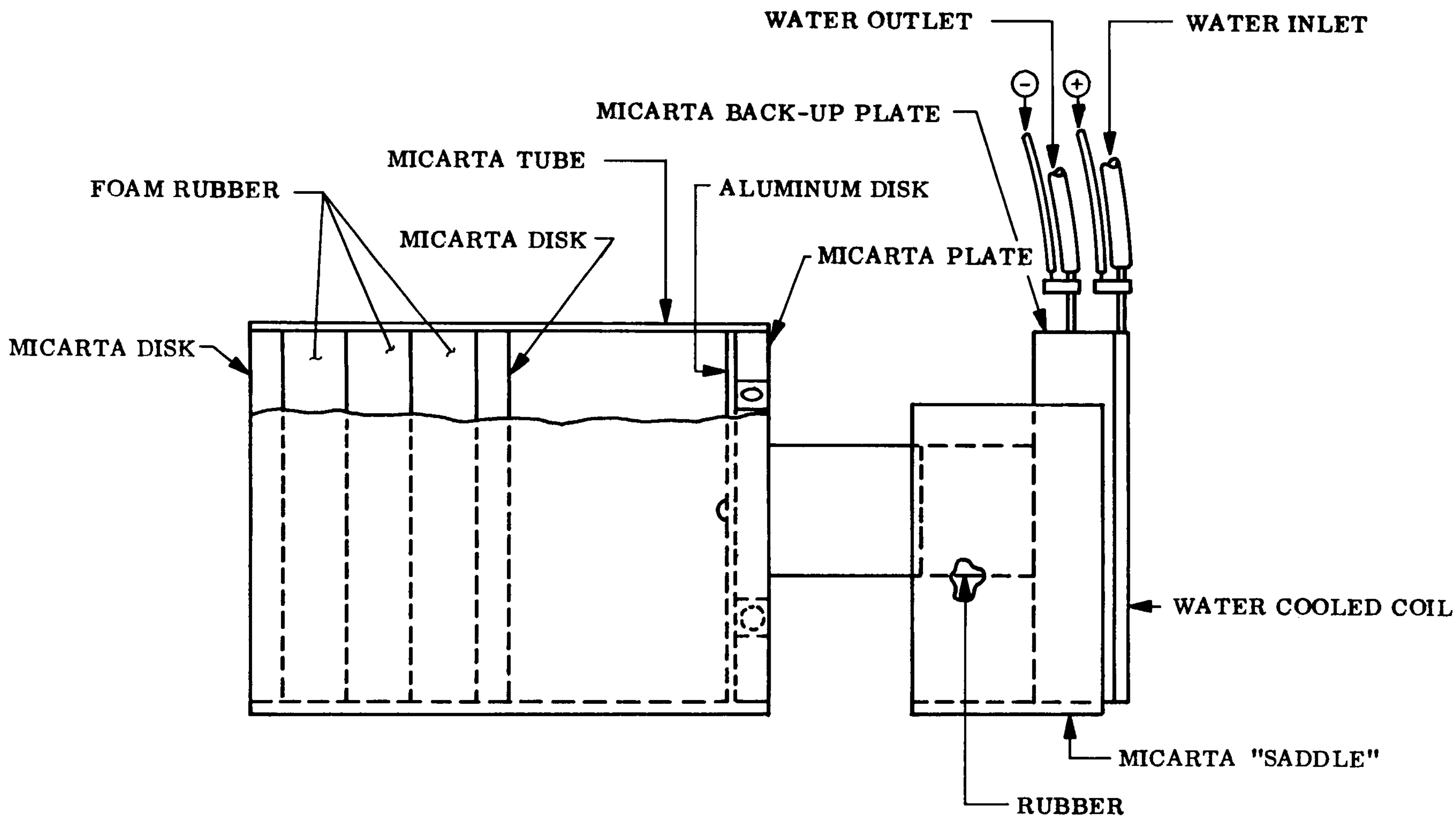


Figure 16. Cross Section of Compressed Air Coil Recoil Assembly

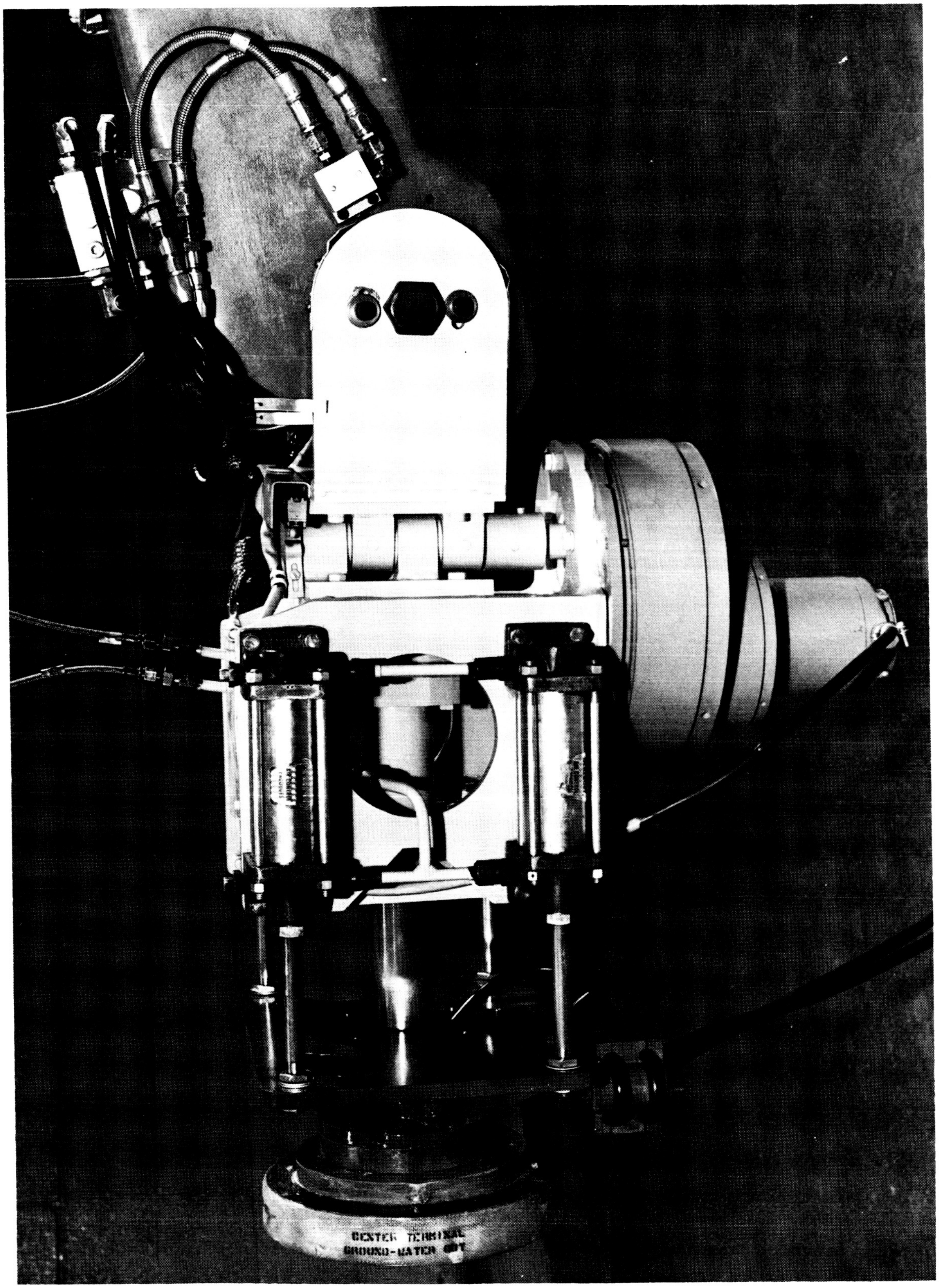


Figure 17. Coil Adaptor and Recoil Assembly

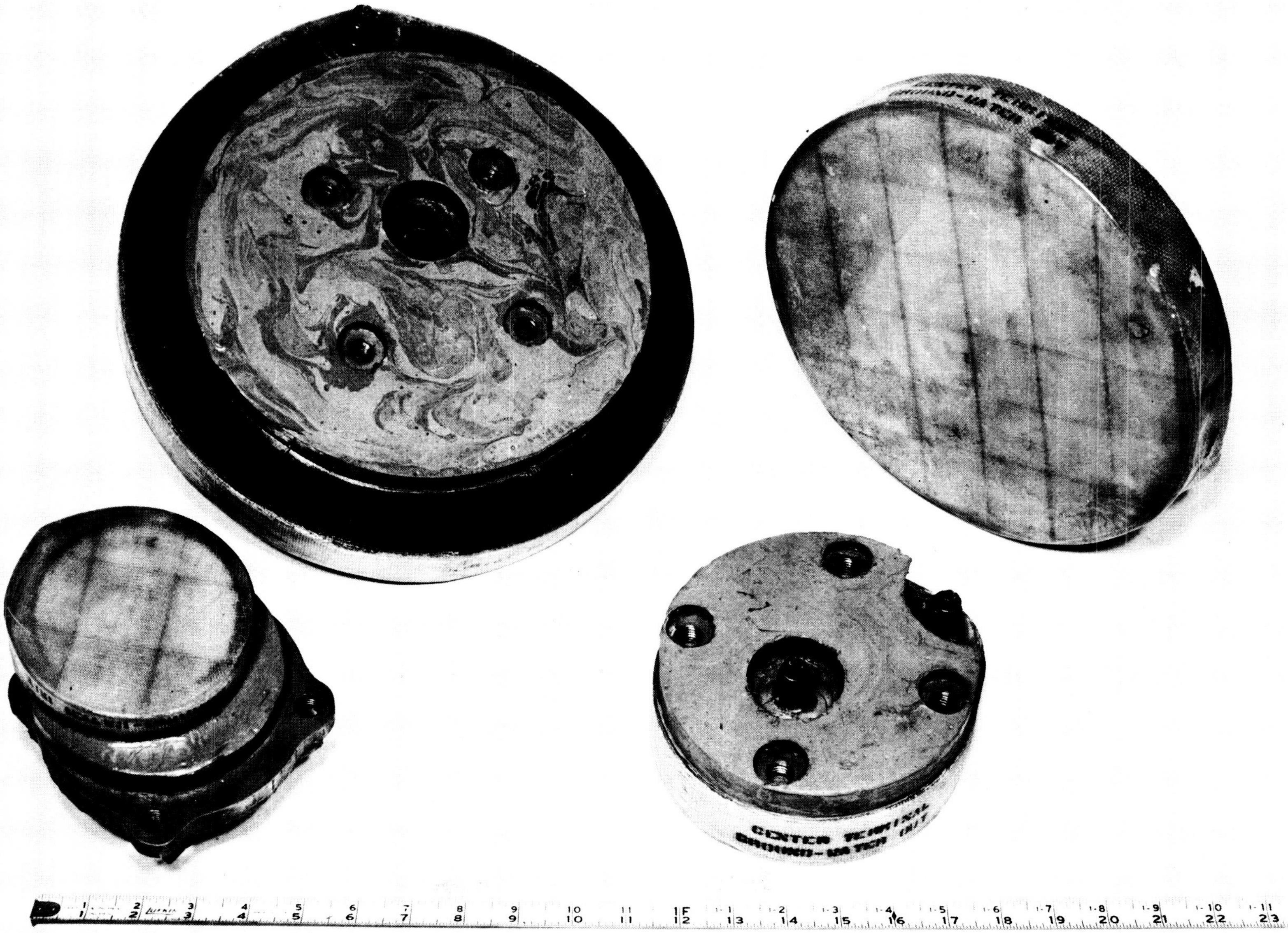
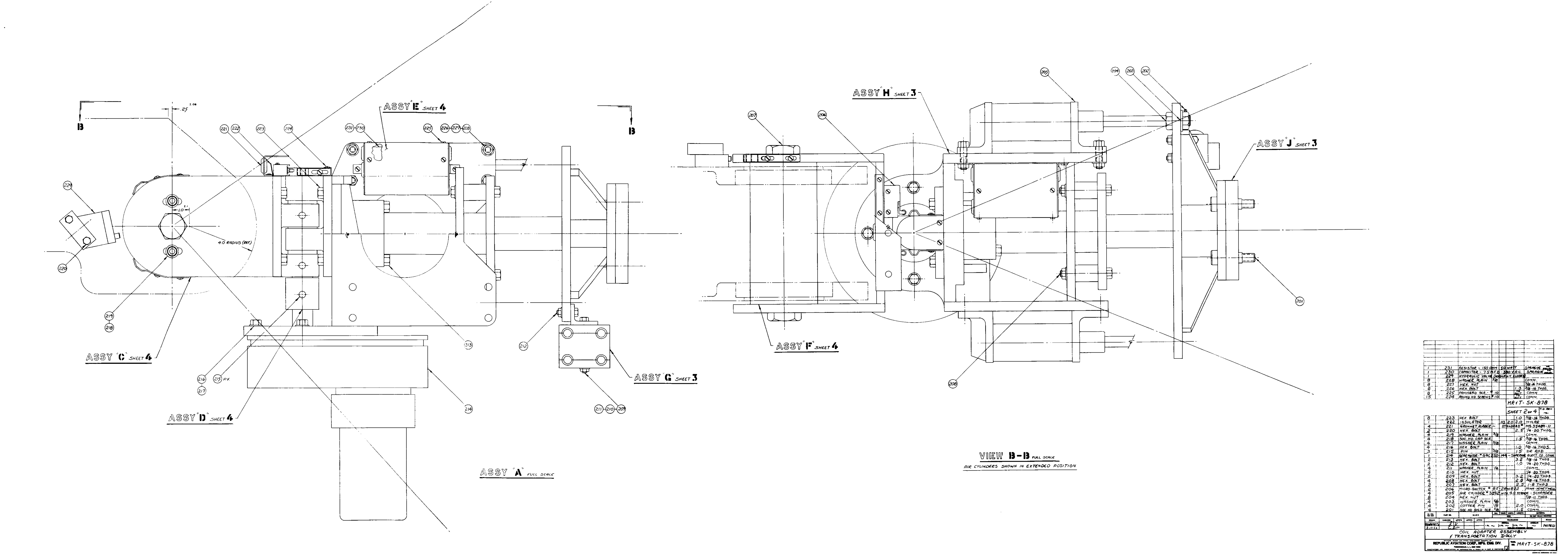


Figure 18. Four-, Six-, Nine-, and Twelve-Inch Diameter Coils

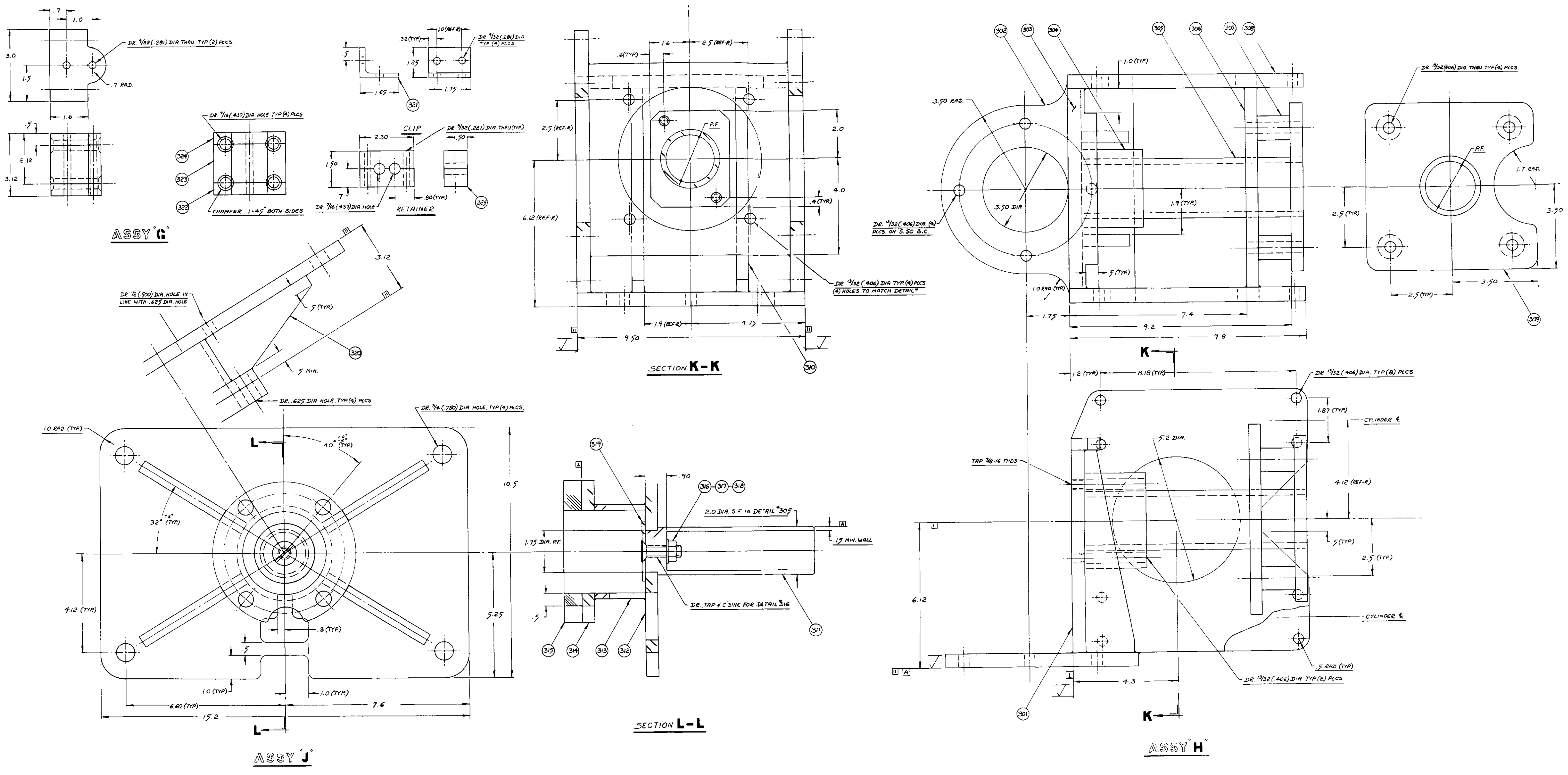


33-1

33-2

Figure 19. Sheet 2, Coil Adapter Assembly and Transportation Dolly

33-3



2	325	BLOCK		.75	1.0	2.4	MICARTA
1	324	BLOCK		.50	2.5	3.0	MICARTA

MR&T-SK-878

SHEET 3 OF 4

1	323	BLOCK		1.75	2.5	3.0	MICARTA
1	322	BLOCK		.50	2.5	3.0	MICARTA
1	321	CLIP				1.8	1/4×2×2 ∠ ST'L
4	320	GUSSET		.50	2.0	5.0	C.R.S.
1	319	WASHER	2.5			.12	C.R.S.
1	318	WASHER PLAIN	1/2				COMM.
1	317	HEX. NUT					1/2-13 THDS.
1	316	FLAT HEAD SCR.				1.5	1/2-13 THDS.
1	315	FACE PLATE		.75	6.0	6.0	MICARTA
1	314	PLATE		.50	6.0	6.0	C.R.S.
1	313	PIPE	3.50			2.0	ST'D. PIPE
1	312	PLATE		.50	10.5	15.2	C.R.S.
1	311	TUBE	2.12			7.0	C.R.S.
2	310	GUSSET		.50	2.0	8.5	C.R.S.
1	309	PLATE		.50	7.0	7.0	6061-T6 ALUM.
2	308	PLATE		.62	9.8	11.0	6061-T6 ALUM.
4	307	SPACER	1.0			1.4	6061-T6 ALUM.
1	306	PLATE		.50	8.0	8.2	6061-T6 ALUM.
1	305	TUBE	2.5	O.D. × .25 WALL			ALUM TUBING
1	304	BLOCK		2.5	3.2	4.0	6061-T6 ALUM.
1	303	PLATE		.50	1.2	8.2	6061-T6 ALUM.
1	302	PLATE		.62	8.0	9.5	6061-T6 ALUM.
1	301	PLATE		.62	8.2	8.5	6061-T6 ALUM.

SCALE FULL

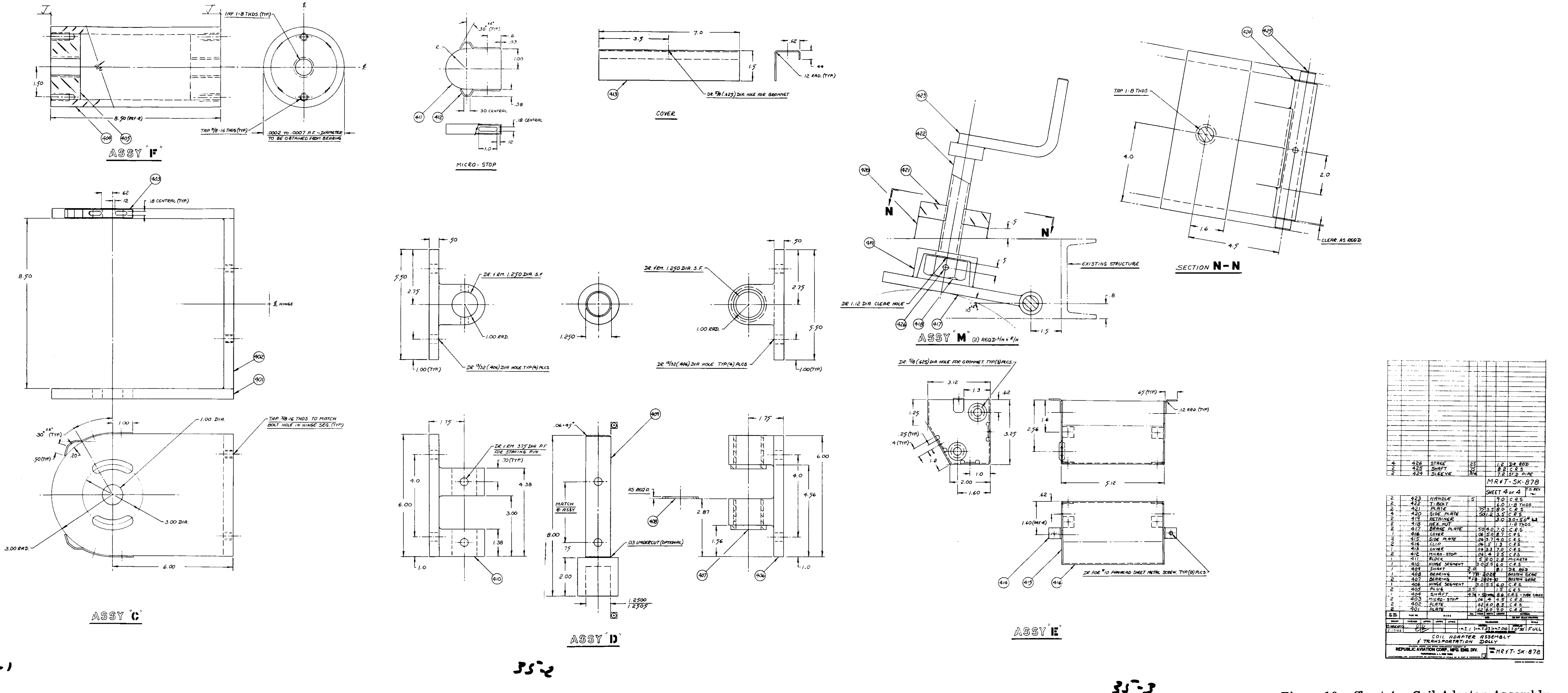
2-17-66

COIL ADAPTER ASSEMBLY & TRANSPORTATION DOLLY

REPUBLIC AVIATION CORP., MFG. ENG. DIV.

TOOL NO. MR & T-SK-878

Figure 19. Sheet 3. Coil Adaptor Assembly and Transportation Dolly



35-1

35-2

35-3

Figure 19. Sheet 4. Coil Adapter Assembly and Transportation Dolly

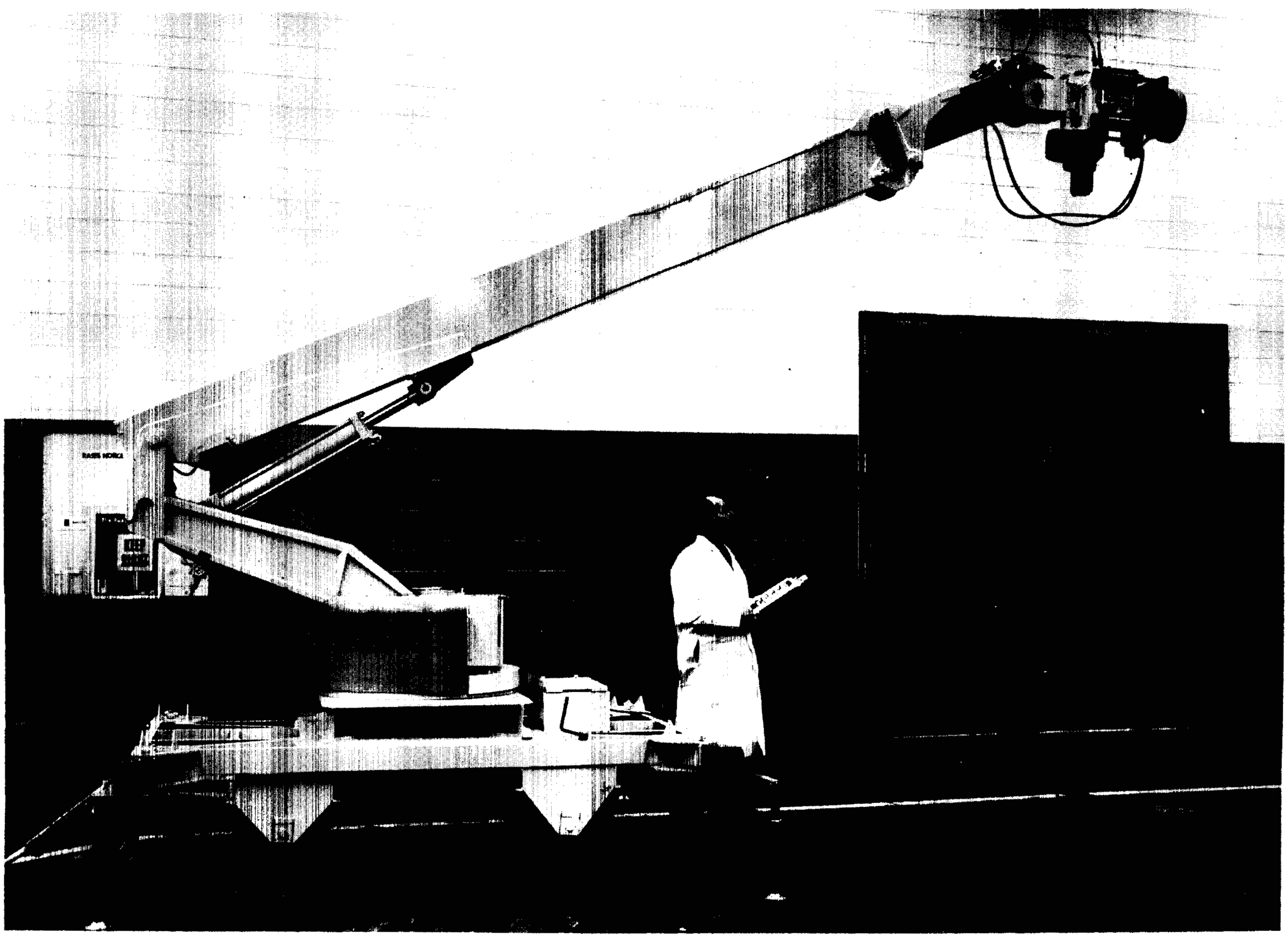


Figure 20. Transporter Dolly Assembly (Boom Retracted)

SECTION 4

TRANSPORTER DOLLY ASSEMBLY

A. GENERAL

The transporter dolly assembly consists of three assemblies as shown in Figures 20 and 21: a trailer, a telescoping boom, and a coil adapter. Two assemblies, the trailer and the telescoping boom, were purchased as a portion of existing equipment and adapted for this contract. The third assembly, the coil adaptor, was designed and manufactured by Republic. The dolly was designed to position and to hold four different size coils (4-, 6-, 9-, and 12-inch diameter) when operating at the maximum 20,000 joule discharge level.

The transporter dolly was designed and fabricated to equal or exceed the following general requirements.

1) Equipped to use any of the four size magnetic coils (4-, 6-, 9-, and 12-inch diameter)

2) Mounted on wheels to provide the necessary mobility and equipped with a brake to provide rigidity when the coil is being used

3) Provide flexibility for locating the coil to the work, i.e.:

   - The coil must translate vertically

   - The coil must translate outwardly from the vertical support; also the axis of this translation must rotate about a horizontal axis which extends through the vertical support member

   - A second axis of rotation must be relatively close to the magnetic coil and permit the coil to rotate in such a manner as to describe a solid cone

See Figure 19 for working area encompassed.

To operate the equipment the following facilities are required:

1) 220 vac, 3-phase, 20-ampere outlet

2) 90 psi air line

3) 50 psi water outlet

4) Water drain

Transportation or movement of the transporter dolly should only be attempted when the boom is in the retracted position. A full description of each of the assemblies mentioned above is presented on the following pages.

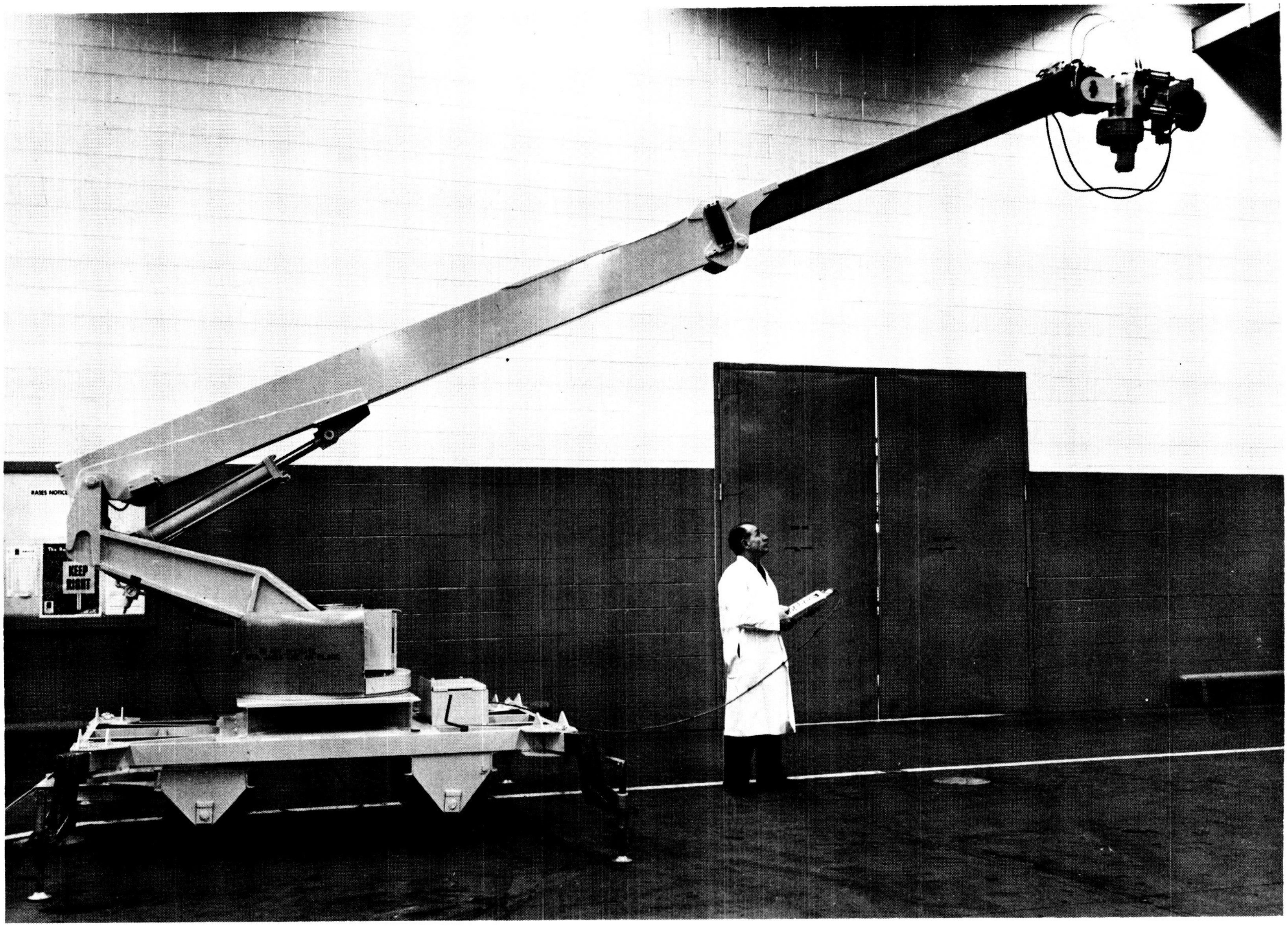


Figure 21. Transporter Dolly Assembly (Boom Extended)

B. MAJOR DOLLY COMPONENTS

1. Trailer

The trailer was manufactured by Jakes Foundry Corporation, Nashville, Tennessee and consists of a modified Model No. 42B. The trailer has a capacity of five tons and is 48 inches wide by 96 inches long, with an open deck construction, having a deck height of 21-1/2 inches. The trailer has a standard three-inch I.D. drawbar ring at the front end and is equipped with pressed-on, solid rubber wheels, 15 inches by 6 inches by 11-1/4 inches having heavy-duty sealed Timken bearings. To facilitate steering, the trailer has a Jakes standard fifth wheel with a large diameter ball race, heavy-duty king pin and Timken tapered-thrust bearing.

The trailer was modified with outriggers (Figure 22) which have sack pads positioned at the corners of a 102-inch square, the diagonals intersecting at the center of the trailer. With the outriggers extended, the trailer will support 250,000 in. lbs. of torque applied at the boom turret (midpoint of trailer).

The trailer also is equipped with a hand brake to lock its wheels (Figure 23).

2. Telescoping Boom

The telescoping boom is a self-contained, telescopic, primarily electrically operated unit manufactured by the Hunt-Pierce Corporation, Milford Conn. The rotation and hydraulic mechanisms are located under fiberglass covers at the base of the turret, and the fly boom extension drive motor is located at the base of the main boom.

Electrical controls are mounted in a remote control box with 50 feet of electrical cable so that the unit can be operated either from the ground at some distance from the trailer or from another vehicle which would be close to the corrective forming operation.

Rotation and fly boom extension is accomplished by electrical brake motors, while elevation is accomplished by an electro-hydraulic system. This hydraulic system is of the "fail safe" type in which a hydraulic holding valve is incorporated on the elevator cylinder. This holding valve will hold the boom in the elevated position if hydraulic pressure is lost.

The boom has dimensions and angles of operation as shown in Figure 19. The boom is capable of the following motions: elevate and depress in the vertical plane about an axis through the vertical support member; extend and retract axially (in telescopic fashion); and swing radially about the vertical support member. These modes of travel allow the electromagnetic coil to translate vertically, outwardly from the vertical support member and about an axis extending through the vertical support member. In addition to the required movements, movement to describe an arc of 135° about the vertical axis of the vertical support is obtainable. This "swing" allows placement of the coil without retraction of the screw jacks and movement of the vehicle.

The coil adapter assembly, which is attached to the end of the boom is free to move vertically and horizontally for fine positioning.

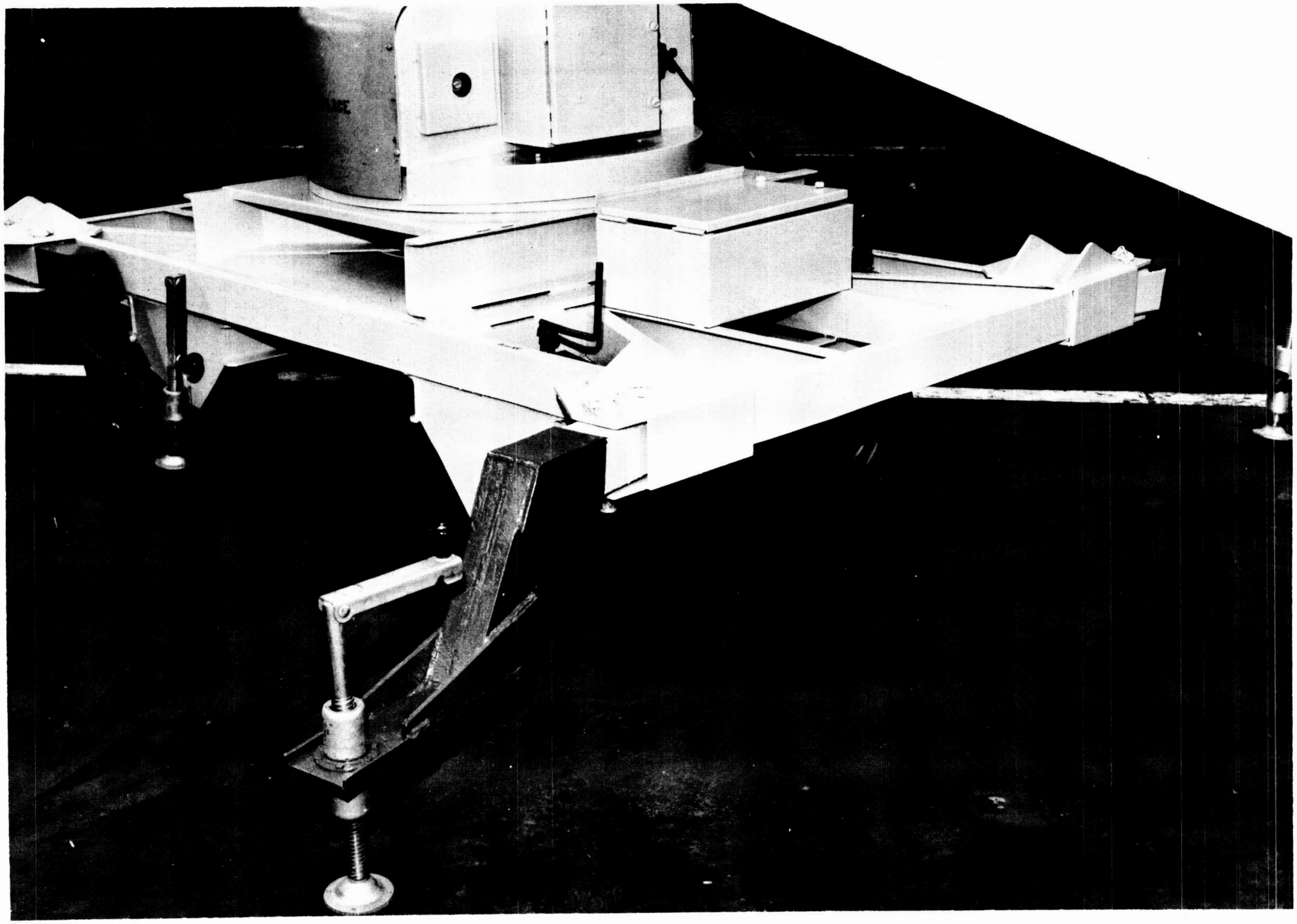


Figure 22. Jack Pads Shown in Stored and Working Positions

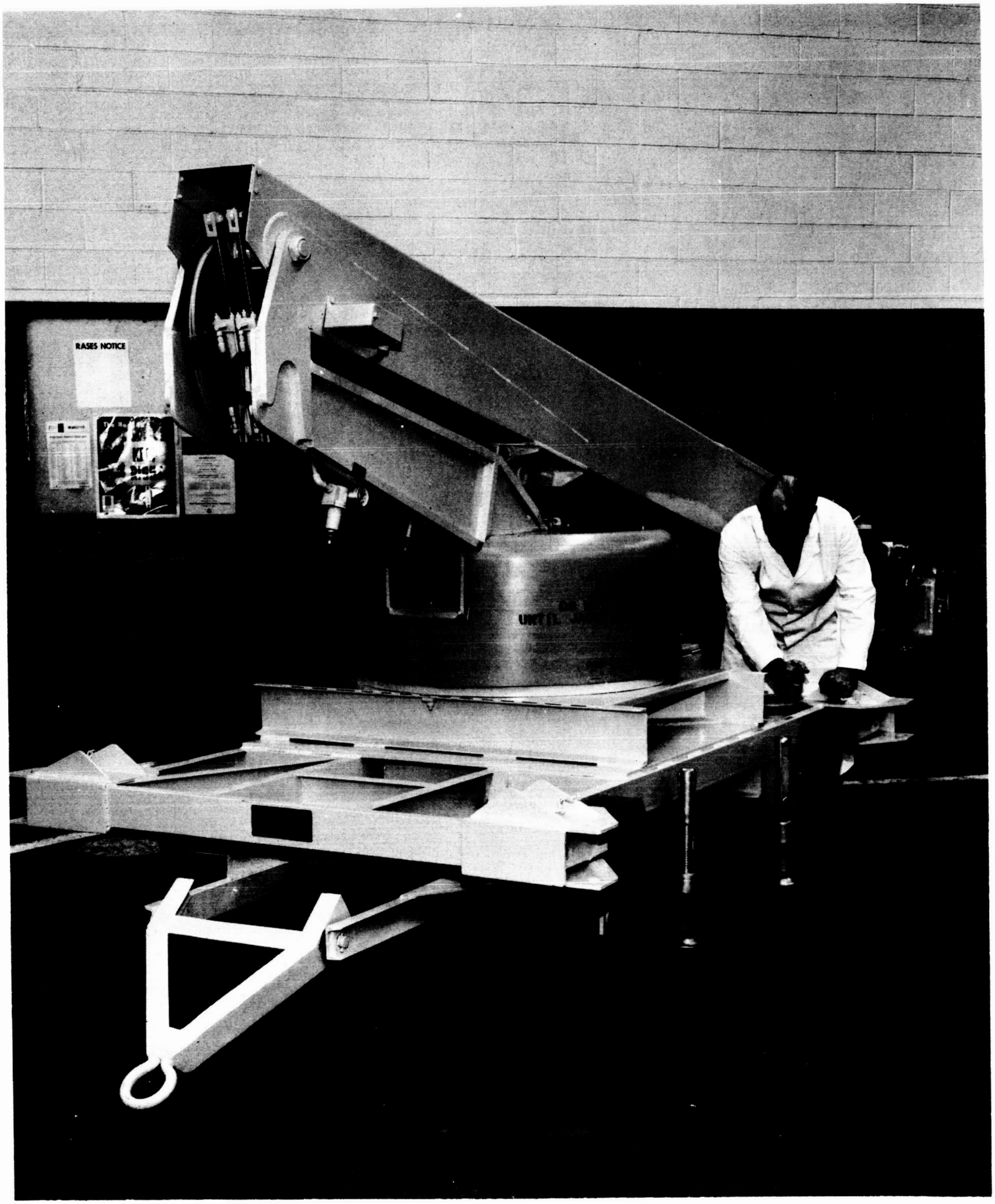


Figure 23. Operating Trailer Brake

SECTION 5

EQUIPMENT OPERATION, MAINTENANCE AND SERVICE

A. GENERAL

Most of the information for this section has been obtained from the Hunt Pierce Corporation, "Servi Lift Model T-31-F Maintenance Manual." Changes and additions to this information have been made to bring the data up to date.

B. EQUIPMENT OPERATION

It is recommended that an inexperienced operator first become familiar with the controls of the unit by operating the jacked up unit in a level area free from obstructions.

Note: DO NOT OPERATE WITHOUT PROPERLY SUPPORTING THE EQUIPMENT AND LOCKING THE BRAKES.

Plug unit into a 230-volt, three-phase outlet and connect a 90 psi air base. The control pendant can now be operated. Check the phase rotation by operating the Elevate Switch to the up position. The boom should go up. If it does not, use the phase reversal adapter plug found in the accessory box mounted on the trailer. The only switches that may be confusing are the Elevate and the Leveling switches which are dependent upon the diverter valve position. When the diverter valve, mounted on the turret, is set in the Elevate position and the Elevate switch on the pendant is operated, the boom will raise or lower. When the diverter valve is placed in the Leveling position, the coil adapter assembly can be leveled or moved up and down in a vertical plane by operating the leveling switch on the pendant.

When learning to operate the equipment, work should be approached cautiously and, as the coil gets closer to the work, short jabs on the switches should be used to complete positioning. To assure the proper positioning of the damping mechanism the following procedure should be adhered to:

1) Operate the air cylinders to position the coil approximately two inches back from the full-out position of the damper cylinders

2) Position coil parallel to and about one inch from the work piece using appropriate positioning controls

3) Operate the air cylinders and clamp the coil to the work piece using pressures between 10 and 20 psi (20 psi applies approximately 250 pounds of clamping pressure). The solenoid valve is held open to maintain pressure during discharge and to return the coil to the work piece after discharging

Note: DO NOT TRANSPORT EQUIPMENT WITHOUT FULLY RETRACTING BOOM.

C. BOOM MAINTENANCE AND SERVICE SECTION

1. Emergency Lowering

In case of power failure which can not be immediately corrected, the boom may be returned to the stowed position as follows:

a) To rotate the booms manually, remove the turret cover over the rotational motor. Refer to Figure 24. Disengage the brake by turning both release studs clockwise against their stops. Rotate the flywheel until the booms are in desired location. Re-engage the brake.

b) To retract fly boom remove the seal and install the emergency fly motor crank through the hole in the brake cover. Then turn the crank to retract the boom (Figure 25).

c) To lower the booms, loosen the check nut and back out the adjusting screw on the holding valve. This allows the bleeding of oil from the elevation cylinder back to the hydraulic reservoir (Figure 26). To reset the adjusting screw, place a rated load (300 pounds in most cases) on the end of the boom and with the booms approximately horizontal, turn in the adjusting screw until settling ceases.

2. Safety

The most important areas affecting safety are the chain and drive system for the fly boom and the lower boom cylinder and attaching parts. See Figures 27 and 28. Failure here could cause a serious accident.

For increased safety factor two independent chains are used to drive the fly boom. It is important that the chains not be set up too tightly, as this constant heavy load could cause early fatigue failure of the drive shaft. It is also important that the fly limit switches be properly adjusted and the fly not be allowed to come against its mechanical stops. This is particularly important in the fly retracted position, as the momentum developed by the fly motor is absorbed in only three or four links of the chain. The stresses developed by this sudden stopping can cause early failure of the chains or bending of the drive shaft.

Good safety practice should include periodic visual inspection of all critical weld areas.

3. Fly Chain Adjustment

The fly chain should not be tensioned excessively. With proper tension the lower section should lie about half way along the bottom of the boom and the upper section should droop about one to one and one-half inches. The chain is tightened by screwing out the adjusting screws in the yoke that supports the idler sheaves near the outer end of the inner boom. Tighten evenly so the droop in both chains is the same. Be sure to tighten the jam nuts after completing the adjustment.

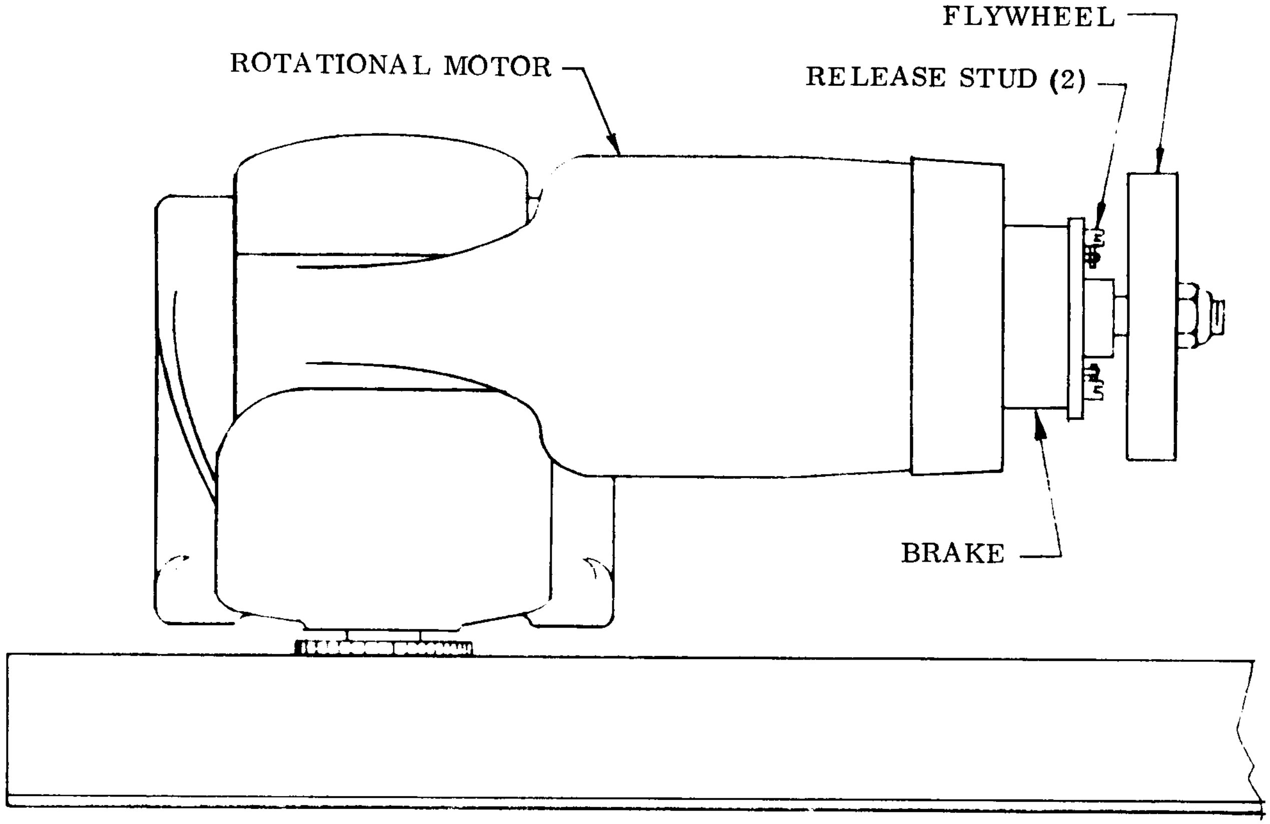


Figure 24. Manual Booms Rotation Diagram

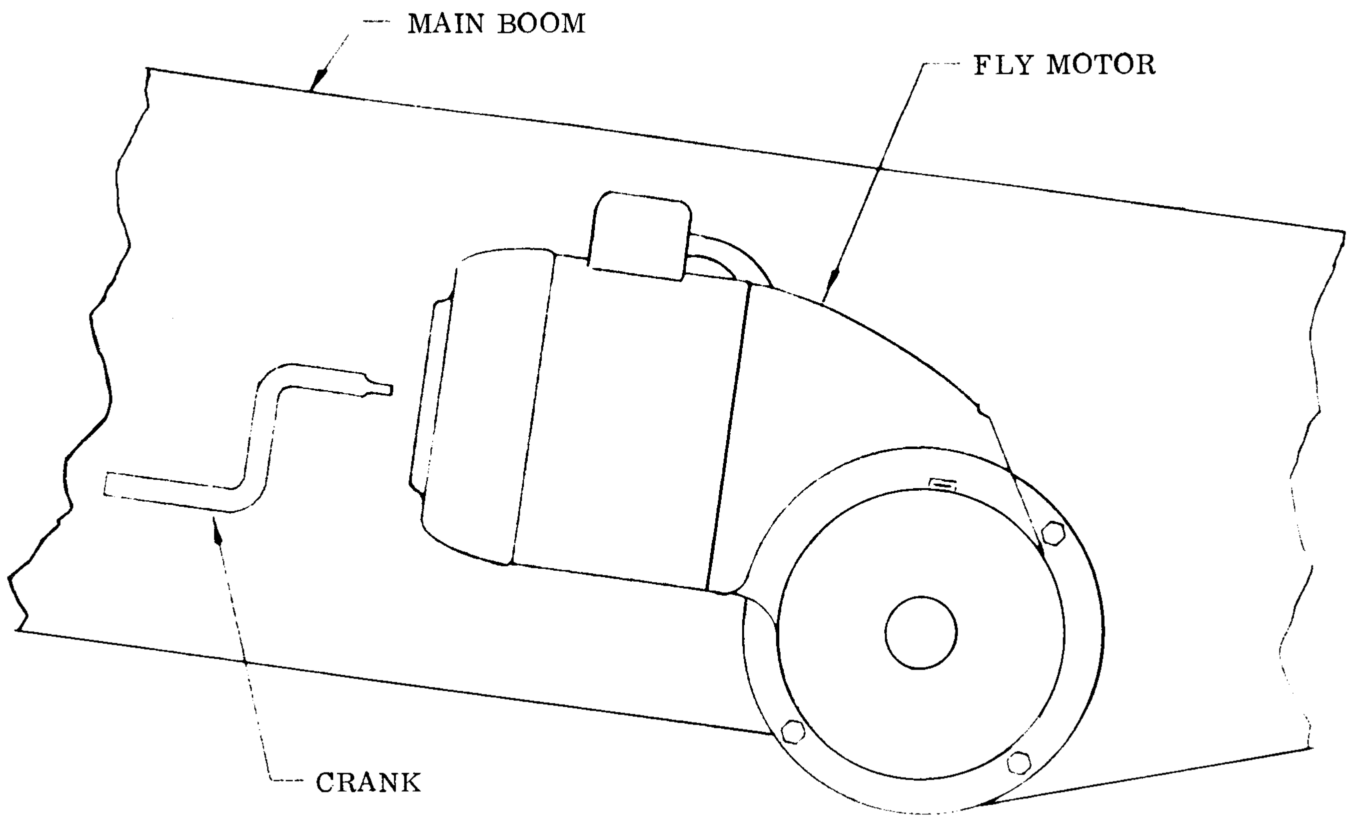


Figure 25. Manual Retraction of Fly Boom Diagram

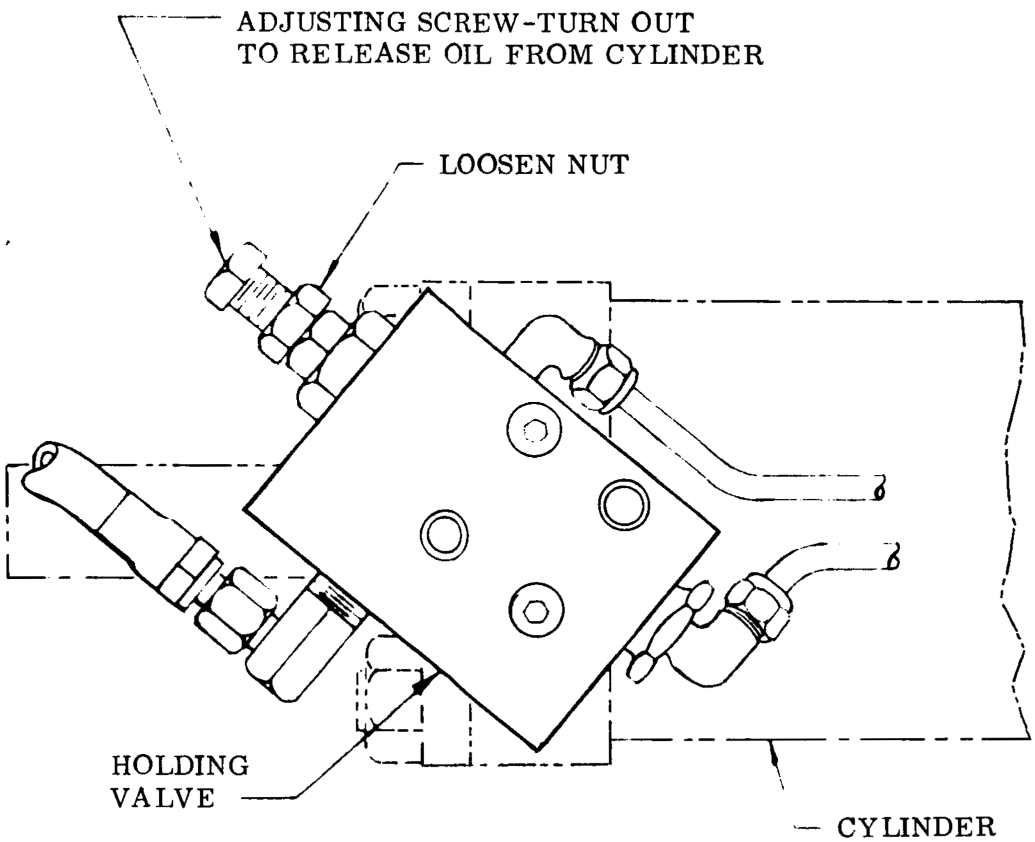
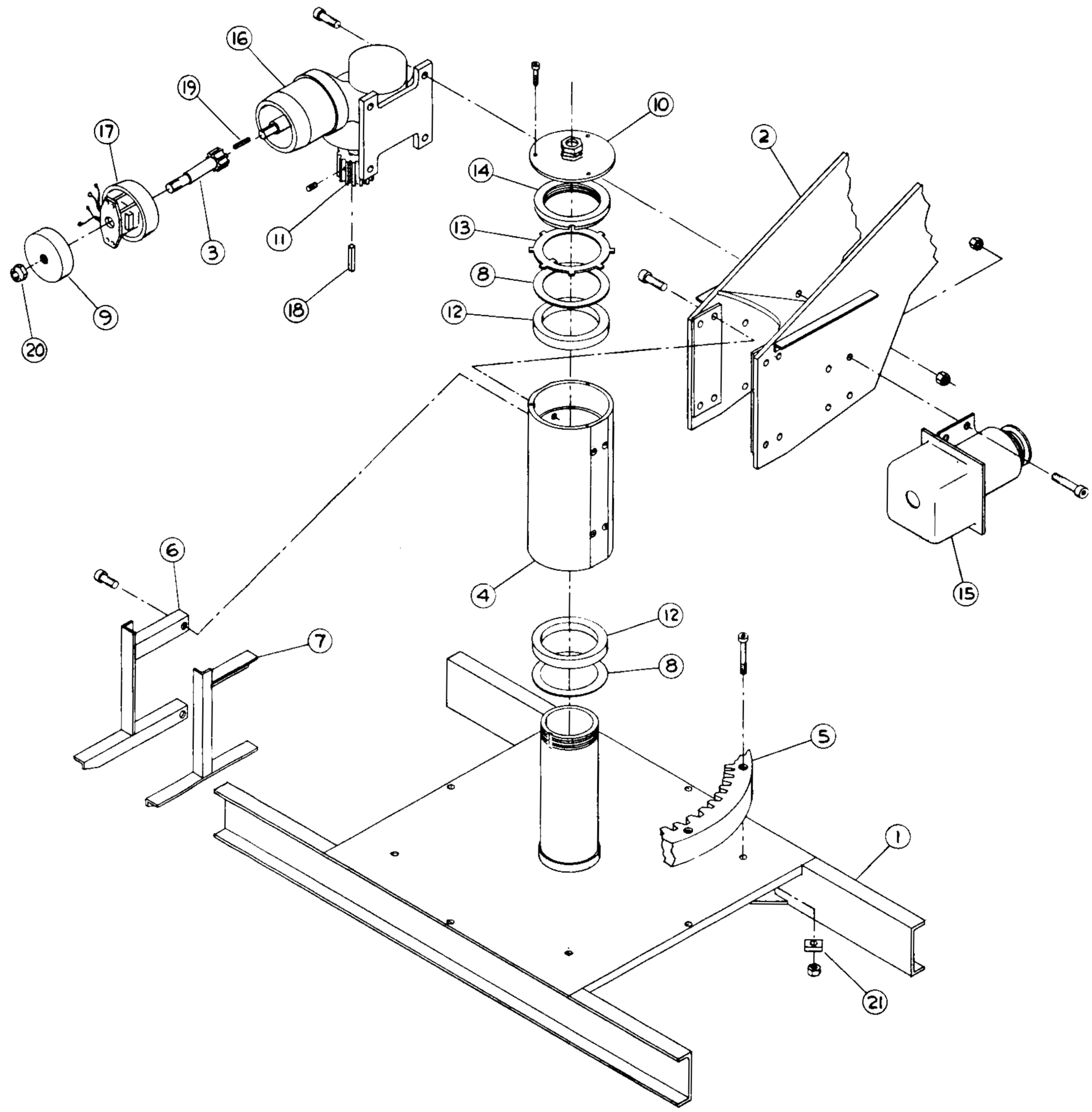
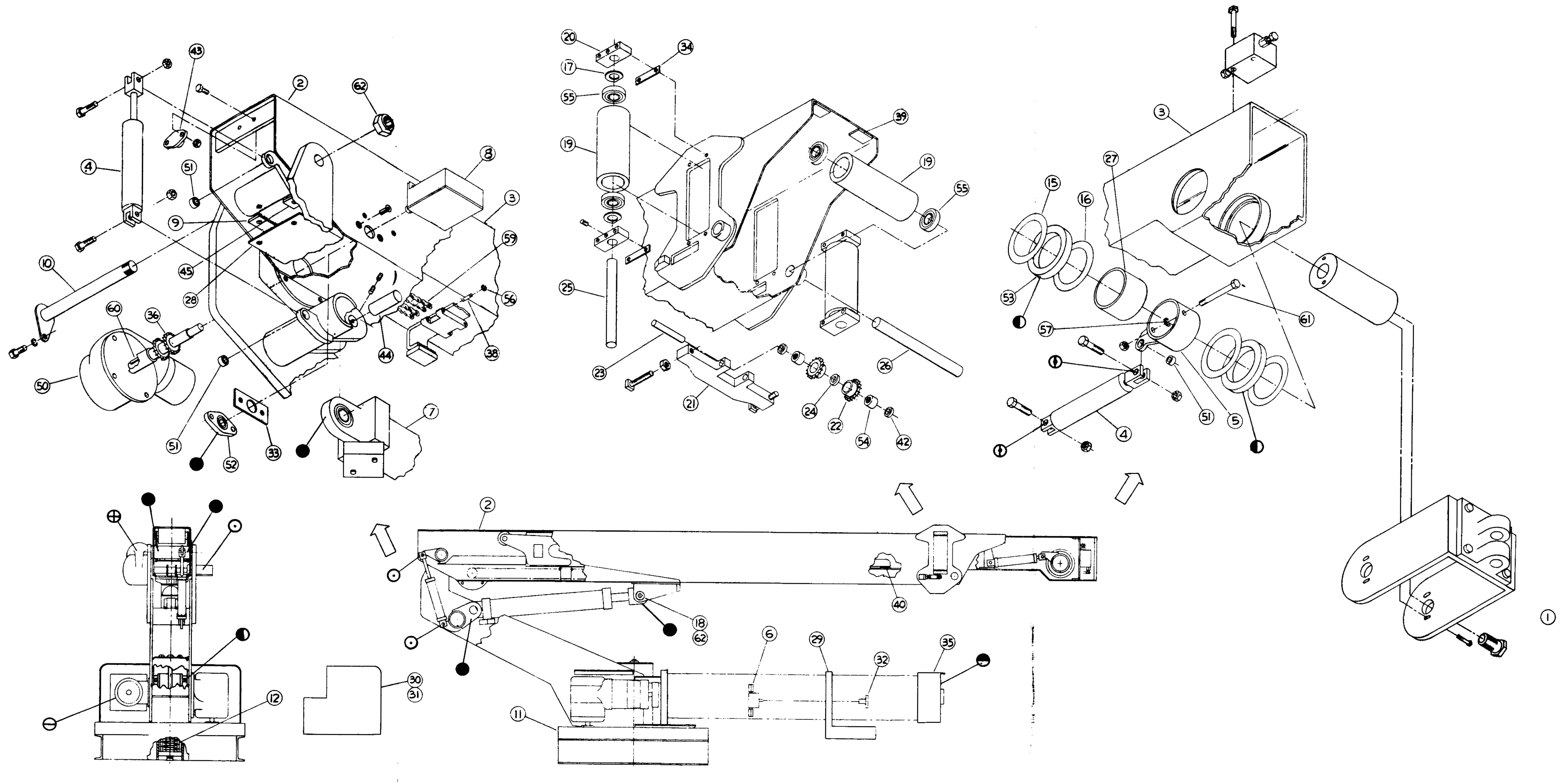


Figure 26. Manual Lowering of Booms



Ref. No.	Part No.	Quan.	Description
1	1-11	1	Turret Assembly, Inner
2	4-3 6-2	1	Turret Assembly, Outer, "T" Models Turret Assembly, Outer, "DT" Models
3	1-48	1	Shaft Assembly
4	4-1003	1	Shaft
5	1-1020-1	1	Gear, Rotation
6	4-15-2	1	Support, Cover, Left-hand
7	4-15-1	1	Support, Cover, Right-hand
8	1-1079	2	Shield
9	1-1129	1	Flywheel
10	1-1121	1	Plate, Cover
11	1-1021	1	Gear, Pinion, Rotation
12	XLS-6	2	Bearing, Ball-Marlin-Rockwell Corp.
13	W30	1	Lockwasher-Tek Bearing Co.
14	AN30	1	Locknut-Tek Bearing Co.
15	GC3500-CA-B30-1	1	Hydraulic System-John S. Barnes Corp.
16	4-1127	1	Motor, Rotational-U. S. Motors
17	R61001S	1	Brake, Magnetic-Dings Brakes, Inc.
18	3/8 x 3/8	1	Keystock-3 inches long
19	3/16 x 3/16	1	Keystock-3/4 inches long
20	3/4-10 UNC-2A	1	Nut, Self-locking
21	3/8	6	Wedge Washer

Figure 27. Turret Assembly



49-1 49-2 49-3 49-4

Ref. No.	Part No.	Quan.	Description
1		1	Bracket Assembly (Non-standard part with attaching bolts)
2	4-4-2	1	Lower Boom Assembly-Model T-31
3	4-5-2	1	Fly Boom Assy. - Fiberglass-Model T-31
4	4-6	2	Leveling Cylinder
5	4-14	1	Bellcrank Assembly
6	4-17	1	Diverter Valve Assembly
7	4-20	1	Cylinder Assembly
8	4-21	1	Box Assembly-Limit Switch
9	4-27	1	Clamp Bar
10	4-34	1	Pin Assembly
11	4-37	1	Turret Assembly
12	4-38	1	Power Feed Assembly
15	1-1081	2	Shield, Outer
16	1-1095	2	Shield, Inner
17	1-1564	4	Spacer
18	1-1654	1	Bolt, Socket Head
19	4-1001-1	3	Roller
20	4-1028	4	Block, Roller Shaft
21	4-1030	1	Yoke, Idler Sprocket
22	4-1032	2	Sprocket, Idler
23	4-1033	1	Shaft, Sprocket
24	4-1034	1	Spacer, Sprocket
25	4-1039-2	2	Shaft, Roller
26	4-1039-3	1	Shaft, Roller
27	4-1049	1	Tube
28	4-1053	1	Tray (With Fiberglass Fly Boom)
29	4-1062	1	Cover, Turret, Rear

Ref. No.	Part No.	Quan.	Description
30	4-1063-1	1	Cover, Turret, Right Side
31	4-1063-2	1	Cover, Turret, Left Side
32	4-1077	1	Knob, Diverter Valve
33	4-1083	1	Spacer
34	4-1084	AR	Shim
35	4-1085	1	Box, Drilled
36	4-1092	1	Shaft & Sprockets
38	4-1097	4	Pin, Chain Attachment
39	4-1098	2	Wear Pad
40	4-1105	1	Wear Pad, Tray
42	4-1108	2	Washer, Yoke
43	4-1109	1	Stop, Fly Boom
44	4-1118	1	Pin, Cylinder to Turret
45	4-1119	AR	Spacer, Tray
50	A520265	1	Motor, Fly Drive-U.S. Motors
51	B8-9L	3	Bushing, Ball-Roller Bearing Company
52	SFT-11	1	Bearing, Flange Unit-Sealmaster Bearings
53	XLS-4	2	Bearing, Ball-Federal Bearings
54	B12-1-12	2	Bearing, Roller-The Torrington Company
55	106-KSZZ	6	Bearing, Ball-Marlin-Rockwell Corp.
56	1000-15	8	Ring, Retaining-Waldes Truarc
57	5133-62	1	Ring, "E" Retaining-Waldes Truarc
58	25720-3	1	Valve, Holding-Sarasota or equivalent
59	ASA#40	AR	Chain, Roller
60	1/4 x 1/4	1	Keystock-1inch long
61	1/2-13 NC	1	Hex head cap screw, steel, 3 inches long
62	1-1/2-12 NC	2	Nut, Self-locking

Key	Lubrication Point	Lubricant	Applied By	Interval
●	Grease Fitting	Lubriplate #630 or equivalent	Pressure Gun	Every 60 days minimum
⊖	Hydraulic Oil Reservoir	Texaco 5W-20 motor oil or equivalent-above 20°F 10W-30 may be used	Fill to within 2 inches of top (with cylinder retracted)	Every 60 days minimum
⊕	Gear Case	Lubriplate #630 or equivalent	Fill to correct level	Check annually
◐	Prepacked Ball Bearings	Lubriplate #630 or equivalent	hand	If disassembled clean and repack
◓	Electrical Controls	CRC 2-26	Spray can	Annually
⊙	Ball Bushing	SAE 20 oil	Oil can	Every 60 days
⊕	Ball Bushing	SAE 20 oil	Oil can	Annually

Figure 28. Telescopic Servi-Lift Assembly and Lubrication Diagram

4. Fly Limit Switch Adjustment

The fly limit switches are mounted on adjustable brackets (see Figure 29). Adjust so that the fly stops 1/4 to 1-1/2 inches from its mechanical stops. To adjust, loosen the locking screw on the bracket to a point where the adjustment is stiff. Adjust switch toward the traveling nut to stop boom further from mechanical stop; away from nut to bring stop point closer to mechanical stop. If this fine adjustment is insufficient, the travelling nut may be rotated in the direction necessary by removing the anti-rotation pin. Turn the nut one turn only and then readjust stopping point with the adjustable switch bracket. Moving the nut will, of course, change both the "in" and the "out" stop adjustments.

5. Fly Roller Adjustment

The side rollers near the end of the lower boom are relied upon to take out the torsion load of the fly boom. These side rollers should make firm contact with the boom. To increase contact, remove one or more shims as required from under the roller shaft support blocks.

6. Rotation Gear Adjustment

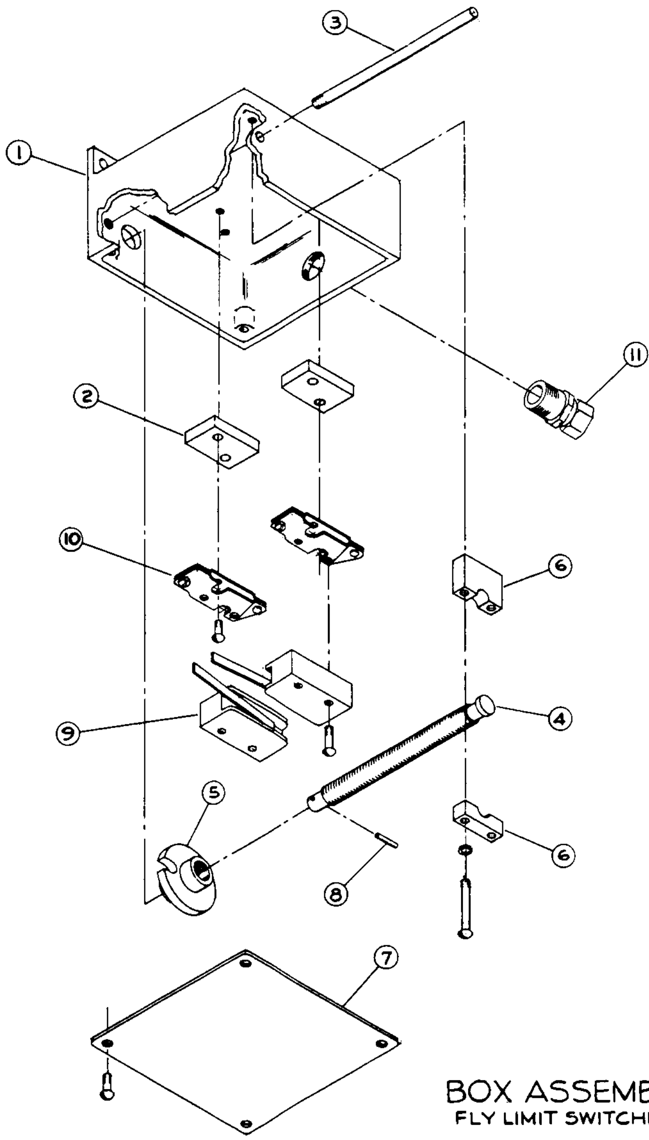
Excessive backlash between the rotation motor drive pinion and the bull gear may be removed by shimming the motor hold-down bolts. Add equal thickness of shims under each bolt. Slight back-lash must be present in all positions of the turret.

7. Hydraulic System

The boom elevation and coil adaptor assembly leveling are operated hydraulically. See Figures 30, 31, 32, and 33.

The boom elevation is operated by a self-contained electrically driven hydraulic power package consisting of a reversible electric motor, a reservoir with submerged pump with necessary relief, and check and make-up valves. No maintenance is normally required other than seeing that the reservoir is kept filled with oil. (See lubrication instructions.) In case of malfunction of this unit, it is suggested that it be replaced and the faulty unit returned to Hunt-Pierce for repair.

In case air is introduced into the cylinder by allowing the oil level in the reservoir to drop excessively, by changing or repairing the cylinder, etc., the hydraulic system should be bled of all air to prevent erratic operation. Bleed as follows: with the cylinder bottomed and the reservoir filled with foam-free oil, disconnect the hose at the holding valve. Operate the boom elevate control and allow oil to flow from the hose until it is air-free. Reconnect the hose and disconnect the hose from the rod end of the dylinder at the pump. Cap the fitting at the pump to prevent entrance of air. A finger may be used. Operate the boom-up control and raise the goom fully, forcing oil and air from the hose at the rod end of the cylinder. The oil may be reused if collected in a clean container and the air is allowed to settle out completely, a process that may take several hours. With the boom in the raised position, reconnect the hose at the pump and disconnect it at the rod end of the cylinder. Operate boom elevate control to the down position and allow oil to flow from the hose until it is air-free. Reconnect the hose. The



Ref. No.	Part No.	Quan.	Description
1	4-1065-1 4-1065-2	1	Box, used on T-26 Box, used on T-31, DT-34, DT-40
2	4-1070	2	Spacer
3	4-1071	1	Pin
4	4-1067	1	Screw
5	4-1068	1	Nut
6	4-1069	1	Pillow Block
7	4-1066	1	Cover
8	156-0625 MBS	1	Spirol Pin, C.E.M. Co., Inc.
9	BZ-2RW80-T	2	Micro Switch; Minneapolis-Honeywell
10	8MA1	2	Adj. Bracket, Micro Switch; Minneapolis-Honeywell
11	2521	1	Strain Relief Connector, Thomas & Betts

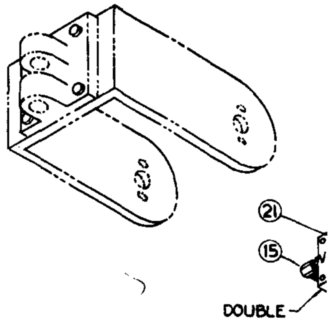
Figure 29. Fly Limit Switch Box Assembly

lower boom hydraulic system is now completely bled. The diverter valve, of course, must be in the elevate position, knob turned counterclockwise, and the reservoir kept replenished with oil as the bleeding proceeds so that no air is introduced. Do not allow the oil level to drop below one-third full.

Coil adaptor assembly leveling is accomplished with a closed hydraulic system. A master cylinder is fastened between the turret back-arm and the lower boom. This is connected to a slave cylinder connected between the coil adaptor shaft and fly boom. These cylinders are interconnected by two coiled nylon hoses. To give a solid feeling to the leveling and to prevent the coil adaptor assembly dropping in case of hose failure, a holding valve is located adjacent to the slave cylinder. As the boom is raised, oil displaced by the master cylinder is added to the slave cylinder, thereby rotating the coil adaptor assembly and keeping it level with relation to the truck deck.

As an aid in bleeding the system, leveling the coil adaptor assembly, the closed leveling system may be connected to the elevation pump circuit by use of the diverter valve. Wehn the diverter valve handle is turned clockwise, the hydraulic pump circuit is switch from its normal function of operating the elevation cylinder to operating the leveling slave cylinder. Switching the elevation control switch will move the coil adaptor assembly up and down in a vertical plain. To take care of excessive pressures in the leveling system due to expansion of the oil caused by temperature rises, or by snagging the coil on some object or the ground, a relief valve is incorporated in each line to the master cylinder. These relief valves are screwed into the diverter valve and dump back into the reservoir.

In case air has been introduced into the leveling system, the following method of bleeding is recommended. Turn the diverter valve to the leveling position. Disconnect the rod end of the master cylinder from the boom fitting. Disconnect the hoses that connect the slave cylinder from the master cylinder. Install a plug in the "full end" fitting of the cylinder. Operate the switch to the "boom-up" position, extending the rod fully. Holding the rod in the out position, operate the control switch to the "down" position for a few seconds until clear, air-free oil comes from the rod end fitting. Now plug the rod end fitting and remove the hose at the diverter valve from the "full end" of the cylinder. While holding a finger over or plugging the end of hose, operate the control switch to the "boom-down" position, retracting the rod fully. Now, with the end of the hose unplugged, reverse the switch to the "up" position and operate it for a few seconds until clear, air-free oil flows from end of the hose. Reconnect the hose to the cylinder. The system is now bled through the master cylinder. Reconnect the rod to the boom fitting and then reconnect the hoses from the slave cylinder. Now remove the end cover from the fly boom and remove the plug from the bleed line from the "full end" of the cylinder. Operate the switch to the "down" position retracting the piston rod fully. Now holding the bucket in this position, reverse the switch to the "up" position and bleed for a few seconds until clear, air-free oil flows from the bleed hose. Plug this bleed hose and remove the plug from other bleed hose. Now operate the switch to the "up" position until the piston rod is fully extended. Holding the bucket in the "dump" position operate the switch to "down" and allow oil to bleed from line until clear and air-free. Replace the plug in the bleed line. The system is now completely bled. During the bleeding operation keep the reservoir replenished with oil. Do not allow the oil level to drop below one-third full.



	Description
	Hose Assembly
	Hose Assembly
	Hose Assembly
	Hose Assembly
	Hose Assembly
	Hose Assembly
	Hose Assembly
04MB*	Hose Assembly
04MB*	Hose Assembly
4MB*	Hose Assembly
4MB*	Hose Assembly
	Hose Assembly Model T-31
	Adapter 1/8 NPTF x 1/8 NPSM x 90°
	Adapter 3/8 NPTF x 1/4 NPSM x 90°
	Adapter 1/8 NPTF x 1/8 NPSM x 45°
	Adapter 1/4 NPTF x 1/4 NPSM x 45°
	Solenoid, Skinner Elec. Valve Co.
	Reducer, Pipe
	Reducer, Pipe
	Tee, Pipe
	Tee, Pipe
	Nipple, Pipe
	Nipple, Pipe
	Plug, Socket Head
	Cap, Pipe, High Pressure
	Adapter 1/8 NPTF x 1/8 NPSM Straight

ELEVATI
CYLIND

Figure 30. Hydraulic System

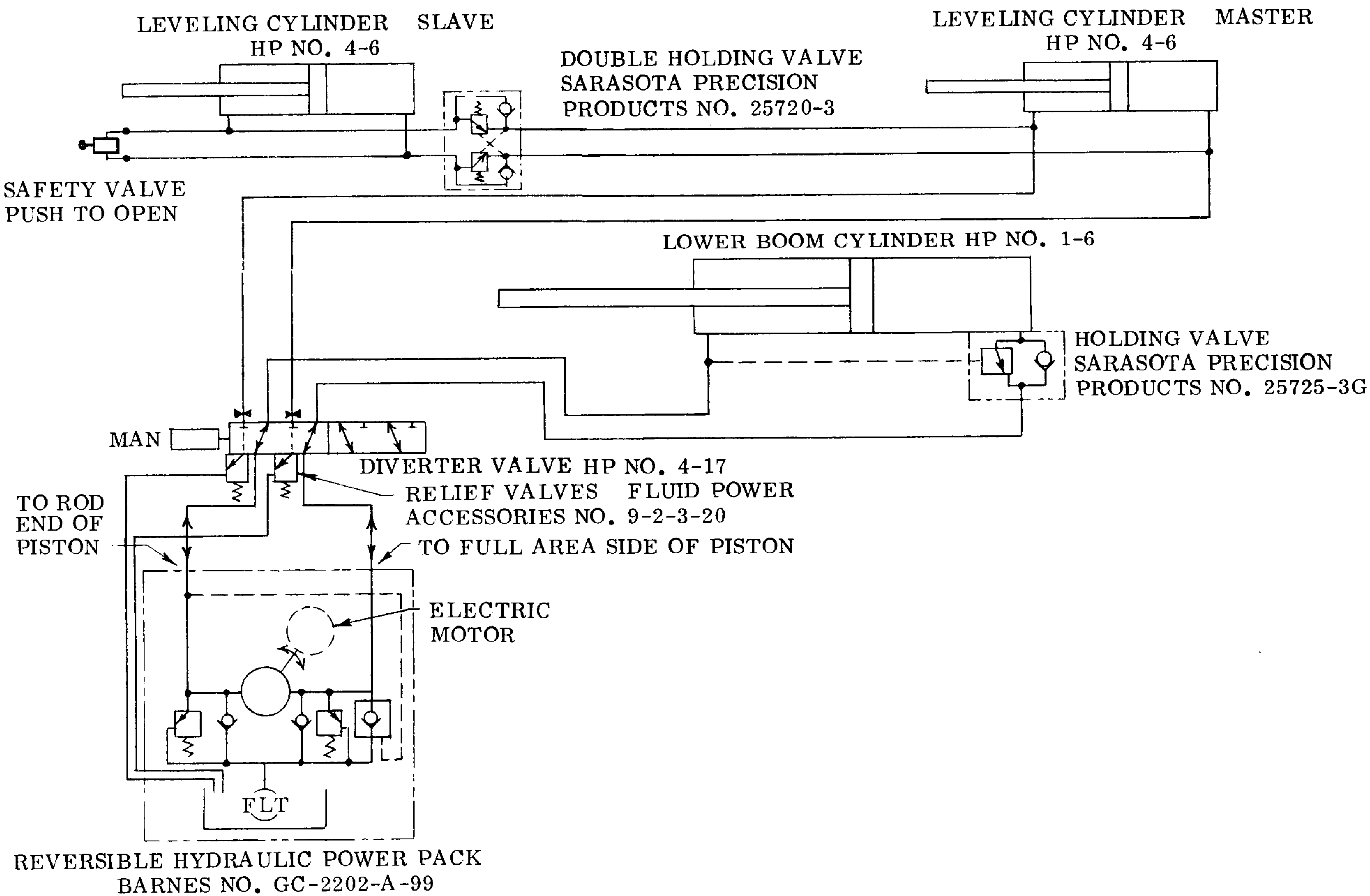


Figure 31. Hydraulic Diagram

8. Trouble-Shooting the Hydraulic System

a. Settling of Booms

Since the hydraulic system has no shut-off valve as such, the boom is prevented from settling with a holding valve bolted to the full end of the cylinder. This valve allows free flow of oil into the cylinder to raise the booms. To lower the booms, sufficient pressure must be built up in the rod end of the boom and through the pilot line to unseat a poppet-type valve held shut by an adjustable spring. If the boom settles, it must be due to leakage in the holding valve or to internal leakage in the cylinder. The cause for settling may be isolated as follows:

1) If the boom settles with a load on the end but does not settle without a load, it indicates the spring adjustment is set incorrectly. To adjust, place a rated load (300 lbs. in most cases) on the end of the boom with the boom horizontal and turn in the holding valve adjusting screw until settling ceases

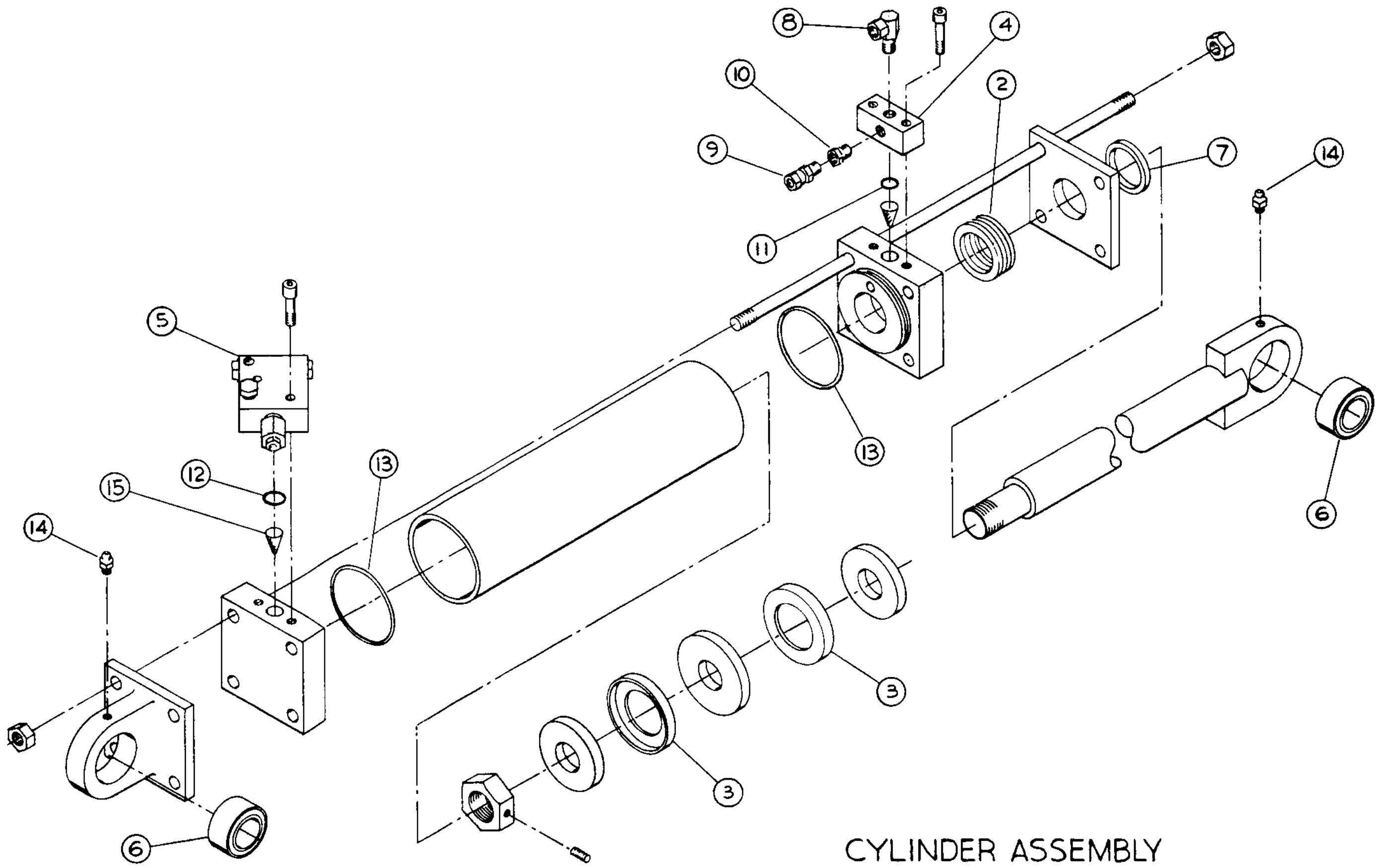
2) If settling is erratic, sometimes settling and somtimes not, it would indicate that foreign matter is being lodged in the valve. If this condition continues, the entire system must be flushed out and refilled with clean oil

3) If the boom settles slowly without much regard to the load on the end, the cause could be wear on the O-ring seal on the pilot piston. To check the seal,raise the boom so the cylinder is supporting a load and remove the hose from the pilot port (the port in the end of the hex nut). If oil seepage from the port is observed, it indicates the seal is worn and needs replacing. To replace the seal (1 1/4 by 3/8 by 1/16-inch O-ring) remove the entire adjusting screw assembly and remove the pilot port fitting. The pilot piston and spring may now be pushed out of the valve through the adjusting screw opening. Oil or grease the new replacement O-ring ring and install it carefully.

4) If the holding valve checks out satisfactorily, then the leakage must be internal in the cylinder. This requires replacement of the cylinder. See Figure 32.

b. Faulty Leveling

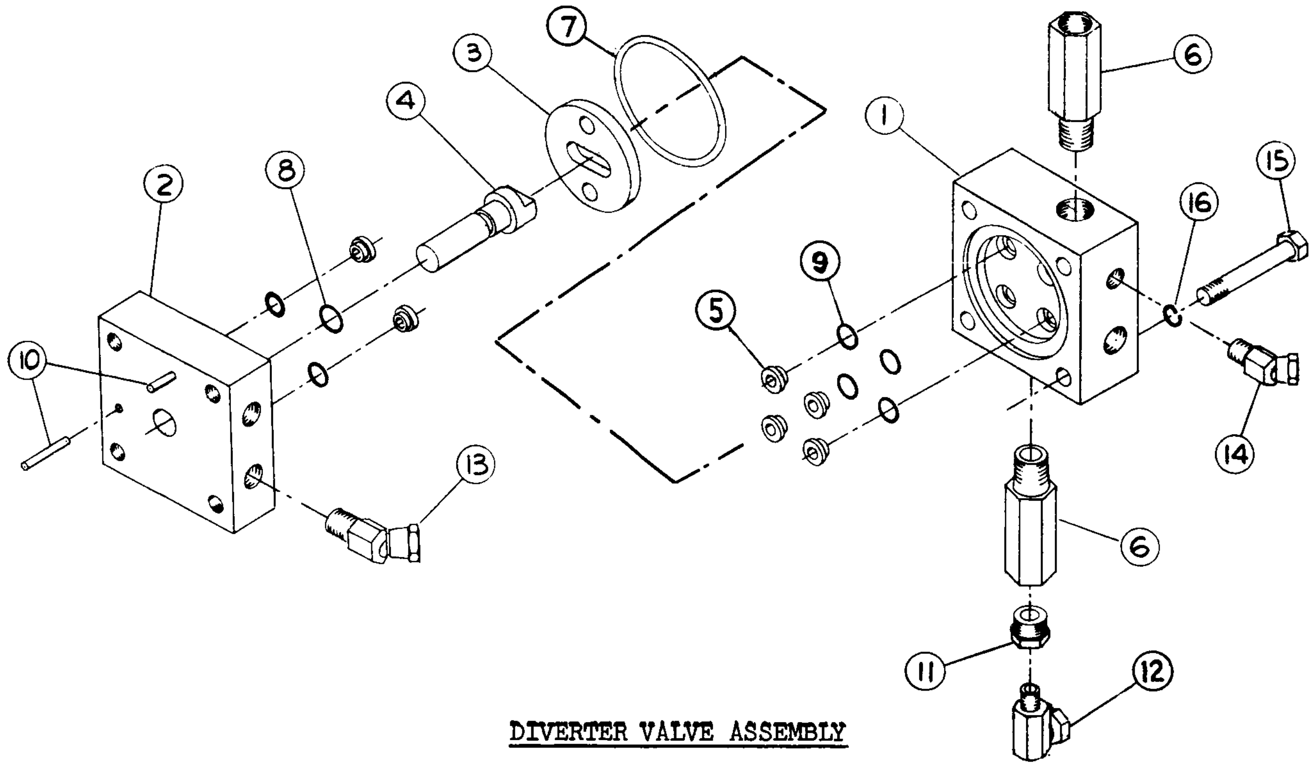
If the coil adaptor assembly tips back and forth with little resistance, it indicates a partial vacuum in the leveling system due to contraction of the oil. To correct the condition, turn the diverter valve to "level" and operate the boom up or down controls to tilt the coil adaptor assembly to each extreme position. Re-level, and return the diverter valve to "boom" position.



Ref. No.	Part No.	Quan.	Description
1	4-20	1	Cylinder
2	1-1184	1	Packing Set
3	1-1185-1	2	Packing, Cup
4	2-1070	1	Plate, Adapter
5	25725-3G	1	Valve, Holding - Sarasota
6	B24-9L	2	Bushing, Ball - Roller Bearing Co.
7	516132	1	Wiper - Chicago Rawhide Co.
8	4MA-4UFS	1	Adapter, Hose - Anchor Coupling Co.
9	2M-2UFS	1	Adapter, Hose - Anchor Coupling Co.
10	110-B	1	Bushing - 1/8 NPT x 1/4 NPT
11	2-015	1	Seal, "O" Ring - Parker Seal Co.
12	2-117	1	Seal, "O" Ring - Parker Seal Co.
13	2-342	2	Seal, "O" Ring - Parker Seal Co.
14	1641	2	Fitting, Grease - Alemite Co.
15	1-1683	2	Strainer

NOTE: Parts not identified are part of Item 1, Cylinder Assembly purchased, semi-complete, from Cross Mfg. Co., Lewis, Kansas

Figure 32. Cylinder Assembly



DIVERTER VALVE ASSEMBLY

Ref. No.	Part No.	Quan.	Description
1	4-1072	1	Block, Bottom
2	4-1073	1	Block, Top
3	4-1074	1	Rotor
4	4-1075	1	Shaft
5	4-1076	8	Shear Seal
6	9-2-3-20	2	Relief Valve Accessories, Inc.
7	2-139	1	Seal, "O" Ring - Parker Seal
8	2-12	1	Seal, "O" Ring - Parker Seal Co.
9	2-11	8	Seal, "O" Ring - Parker Seal Co.
10	188-0875	2	Pin, Spirol
11	110-B	2	Bushing - 3/8 NPT x 1/8 NPT - Imperial Brass Mfg. Co.
12	2MA-2UFS	2	Adapter, 90° - Anchor Coupling Co.
13	4MAX-4UFS	4	Adapter, 45° - Anchor Coupling Co.
14	2MAX-2UFS	2	Adapter, 45° - Anchor Coupling Co.
15	5/16-18 UNC	4	Hex Head Cap Screw-2" Long - Steel
16	5/16	4	Lockwasher, Steel

Figure 33. Diverter Valve Assembly

Creeping of the coil adaptor assembly in one or both directions with the boom stationary indicates either internal or external leakage. Check all connections back as far as the diverter valve for external leakage. If there is no appreciable external leakage, next check the holding valves. To check, turn the diverter valve to "level" then check to see if the coil adaptor assembly creeps with a 200-pound weight on the end of the assembly. Check in each direction. If the assembly creeps, slowly turn in the adjusting screw on the holding valve section to which the hose from the outlet (leaking) side of the leveling cylinder connects. Turn in just far enough to prevent creeping. If this does not stop the creeping, the trouble may be further isolated by removing the cylinder-to-holding-valve hoses at the cylinder and then plugging. If the bucket still creeps, the leakage is past the piston in the cylinder. Repair or replace the cylinder. If it proves to be in the holding valve, repair or replace the valve. See Section 8a above for further instructions for repair of holding valve.

If the coil adaptor assembly after proper leveling does not creep with the boom stationary, but becomes further and further off-center as the boom is raised and lowered, it indicates leakage either through the diverter valve or the relief valves or internal in the lower "master" leveling cylinder. To check further, with the diverter valve in the "boom" position, disconnect the leveling hoses from the diverter valve. Cap the hoses. Now run the boom up and down. Check to see if there is any appreciable leakage through the open diverter valve ports. If the leakage exceeds 10 drops per minute, the valve should be repaired or replaced (Figure 33). If the diverter valve is not leaking, reconnect the leveling hoses and disconnect the hoses from the relief valves (the hexagonal valves screwed into the diverter valve). Run the boom up and down. There should be no leakage past the relief valves. If the relief valves leakage must be past piston in low "master" leveling cylinder. Repair or replace cylinder.

9. <u>Slow Operation</u>

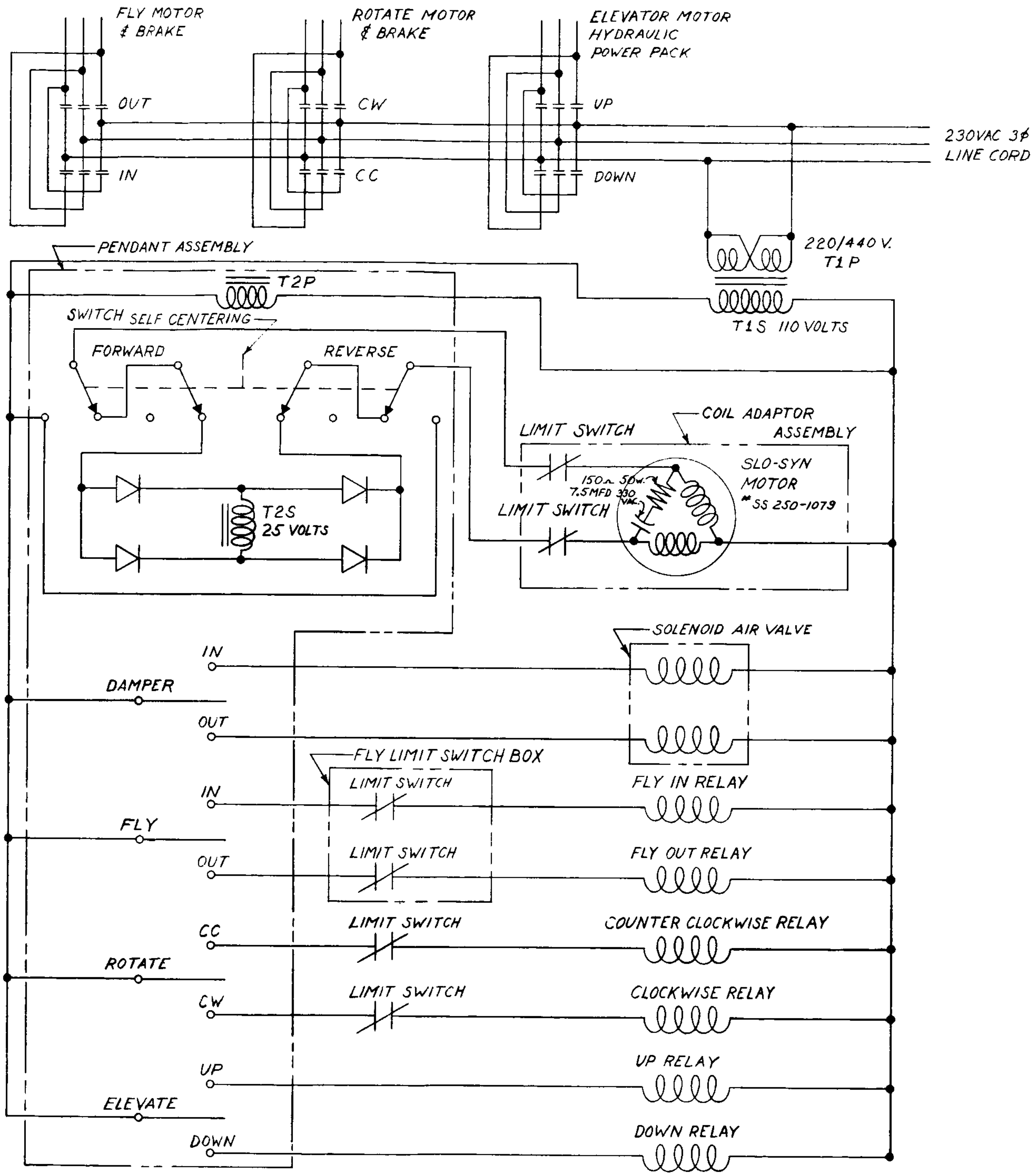
If all motions of the unit seem slow, check to see if the voltage is sufficient. It should be between 130-145 volts (Phase to Ground).

If either the fly or the rotation seem excessively slow, it could be caused by the magnetic brake not releasing. This may be checked visually, If faulty, check the brake wiring and for signs of brake coil burn out. If the coil is shorted or burned, the brake must be replaced.

If the booms are slow to come down, the probable cause is that the holding valve is set up too tightly. Readjust the valve so the booms will just start to settle when the rated load is exceeded in the bucket.

10. <u>Electrical System</u>

WARNING: The telescopic boom assembly operates on 230-volt, 3-phase current. For safety, disconnect the main feed line by unplugging it from the supply box before working in the control boxes or motor connection boxes. Figure 34 is electrical schematic of the booms assembly,



NOTE:
ALL ITEMS NOT ENCAPSULATED WITH PHANTOM LINES ARE LOCATED IN THE TURRET AREA

Figure 34. Electrical Schematic

11. Lubrication (Figure 29)

Lubricate the ball joint at each end of the boom cylinder and the ball joints attaching the boom to the turret back-arm.

The rotation bull gear should be kept free of debris that might jam between teeth and lightly coated with a good grade of grease.

The rotation and fly motor gear cases are filled with a medium ball bearing grease. Refill annually with a grease gun until grease is forced from vent holes.

Hydraulic reservoir: Keep filled within two inches of top (with cylinder retracted) with a 5W-20 motor oil of a reputable refiner. 10W-30 oil may be used if the unit will not be used in temperatures below 20°F.

The fly boom rollers have life-time sealed ball bearings.

The fly drive chains are of the permanently lubricated type with oil impregnated sintered steel bushings and require no lubrication.

The flange bearing on the outboard end of the fly drive shaft has a grease fitting ahd should be lubricated with a good grade of medium ball bearing grease annually.

The ball bearing attaching the coil adaptor assembly to the fly boom have shields and are packed with grease. If for any reason it is necessary to remove the coil adaptor assembly, it is recommended that bearings be removed, cleaned, and repacked with a high-grade medium ball bearing grease before reassembly.

SECTION 6

CONCLUSIONS

1. Water-cooled coils capable of firing at 15,000-joule energy levels and a repetition rate of one discharge every ten seconds can be designed and manufactured to have a useful coil life.

2. Rapid firing with high-energy-level discharges can be accomplished using water-cooled electrical feed cables.

3. Water cooling is the most efficient method of cooling the coils, even though it requires an additional facility to operate the equipment.

4. Mechanical terminal failures experienced at the coil are eliminated by combining the water and electrical connections into one specially designed end fitting. Use of this fitting also simplifies interchanging of coils.

5. The rate of firing affects the coil cooling water temperature more than the level of the energy being discharged.

6. Electrical insulation breakdowns at the coil windings can be prevented using an insulation material with a specifically developed method of applying the material to the windings.

7. The positioning mechanism is protected from shock during the discharge by the air damping assembly. This assembly also holds and final-positions the coil to the work piece.