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DEVELOPMENT OF A TECHNIQUE FOR FORMING HELICAL COILS

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16. Abstract

The objective of this program was to perform a study of several probable forming techniques for fabricating a 200 turn helical coil for use as the recording surface on a helical tape recorder.

As a result, this was to review the several methods of forming helical coils and to select the most probable and practical technique and show the feasibility of the method by producing a coil of each type.

The technique selected for fabricating the helical coils was the use of a rolling mill. The tape is fed between two driven rolls and by varying the pressure between the rolls and changing the angle of the top roll in relation to the bottom roll, tapes of various diameters are formed.

This technique of forming the helical coils produced samples which proved the feasibility of the technique.

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PREFACE

The objective of this program was to develop a technique for forming 200 turn helical coils for use as the recording surface on a helical tape recorder.

The tape material was beryllium copper alloy 25 and the coils were made in accordance with GSFC drawing GC1070548, Revision C.

This program consisted initially of a study phase to survey the field for the most probable and practical technique for forming a helical coil. Meetings were held and various methods were reviewed. The decision was made to produce the helical coils by a rolling mill technique.

A rolling mill was designed and fabricated to produce both 1/4" and 1/2" wide helical coils as per the above drawing.

After the mill was assembled and tested, minor difficulties were experienced. The first was the pickup of chatter marks on the surface of the tape. This was due to the gear drive consisting of two sets of stock spiral bevel gears. This drive system was changed to a worm and gear drive which eliminated the chatter. The second problem area developed in the two rear bearings. The top roller used a self aligning roller bearing and the bottom roller used a barrel roller bearing. Because of the tolerances in these bearings, the uniformity of the inside diameter of the helical coils could not be maintained. These bearings were replaced with solid bronze bearings the same as used on the two front supports bearing.

With these modifications, the machine was set up to produce helical coils. After several attempts at fabricating coils it was discovered that the only way to produce the 1/4" wide helical coil, 5" and 10" in diameter, was to roll two thicknesses of tape simultaneously. Using this technique, a 1/4" wide helical coil 10" inside diameter was rolled. When approximately 75 continuous turns were rolled, the diameter changed significantly. This was due to the gear drive generating enough heat in the rear bearing housing to cause a dimensional change in the roll setting and in the coil being made.

The machine was again set up to produce a 1/4" wide 5" inside diameter helical coil and after approximately 30 turns were produced, the same heat problem caused a change of the inside dimension of the coil.

The machine was again set up to produce a 1/2" wide 10" inside diameter coil using one thickness and two thicknesses of tape. After several attempts to roll, it was concluded that the machine did not have the capacity to apply enough pressure to the work rolls to roll the desired helical coil and not enough power to drive the rolls at the necessary pressures.

The original calculations were reviewed and they showed that the machine was designed to produce sufficient pressure and power to make the required helical coils. The formulas for rolling metals from which these calculations were based may be off by a factor of 10 or more when applied to very thin materials. These formulas were developed and are used for thicker and wider straight plate and sheet stock.

Using the rolling mill, attempts were made to make an impression of the rolls across the width of the 1/4" and 1/2" wide tape stock. Pressure was applied to the work rolls until the 1-3/4" diameter roll shafts were bending to the degree that the roll imprint covered only 1/2 of the tape width.

Our recommendations to make this forming technique work consists of two changes to the rolling mill. The first change consists of separating the gear drive from the main housing and driving the two rolls through universal joints; this would eliminate heating the rear bearings. The second change consists of installing two bearings to support the overhung rolls which would prevent the shafts from bending and would evenly distribute the pressures across the width of the tape.

A. INTRODUCTION

The purpose of this program was to develop a technique for forming helical coils for use as a recording surface on a helical tape recorder.

The program consisted of a study phase to determine the most probable and practical technique and to show the feasibility of this technique by producing helical coil tapes of various widths and thicknesses.

The various methods studied included Edge Rolling (a method proposed by the Torrin Manufacturing Company), Rolling Mill (which was used on a previous contract to product 50 helical coil tapes 1/8" wide, 5" inside diameter, 200 turns), Extruding, Casting, Joining, Machining, and Forming.

The methods were reviewed and eliminated on the basis of practicality, development cost, and end product requirements. The decision to produce the helical coils by the rolling mill technique was determined to be the most suitable for the various size coils required.

A rolling mill was designed, fabricated and small samples of tapes were produced. However, it was determined that the rolling mill as designed did not have the pressure capacity or the power to produce dimensionally stable coils using single strips of stock material. Recommendations were made as how to modify the rolling mill to eliminate the problems in the present design.

B. Study of Various Techniques

This phase of the program consisted of a study of the various methods that could be employed to fabricate helical coils.

The material selected for these helical coils was beryllium copper alloy 25, and the coils were to be in accordance with GSFC drawing GC1070548 Revision C. The dimensions of these coils are as follows:

Thickness of tapes	0.003" and 0.005"
Widths of tapes	0.250" and 0.500" 0.000"
Inside diameters of coils	5.000" and 10.000" $\pm$0.015"

As proposed in our proposal the two main techniques that were to be investigated were edge rolling and flat-taper rolling. However, several other methods such as Machining, Casting, Forming and Joining were looked into.

1. Edge Rolling (Figure 1)

This technique was developed by the Torrin Manufacturing Company for fabricating the 1/8" wide, 0.005" thick, 5" inside diameter helical coils.

A visit was made to the Torrin Company where the use and advantages of this technique was discussed with Mr. Robert Carlson and Mr. Robert Cawley. They were rather reluctant to divulge the details of this technique because of the possibilities of industrial applications they may have.

This technique consists of a mandrel which is used to pull the tape through a series of rolls to give the tape some shape. The main force and final shape given to the tape is by the rotating mandrel used as a capstan. The forming of a helical coil by this method actually draws the metal through the forming rolls; however, the rotating mandrel (capstan) applies pressure to the inside edge

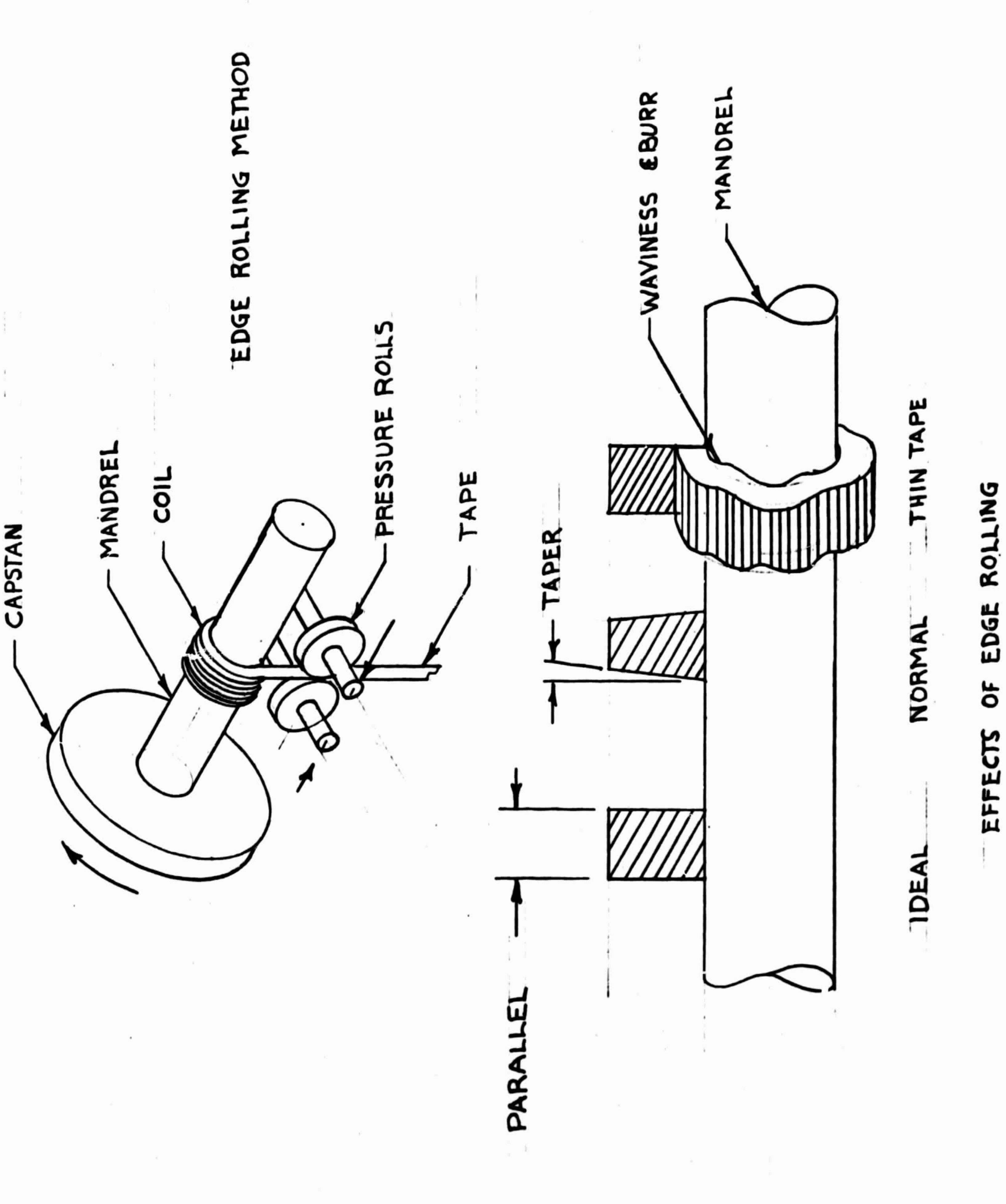

EDGE ROLLING METHOD
CAPSTAN
MANDREL
COIL
PRESSURE ROLLS
TAPE
EFFECTS OF EDGE ROLLING
IDEAL
NORMAL
THIN TAPE
PARALLEL
TAPER
WAVINESS & BURR
MANDREL

FIGURE 1

of the coiled tape and has a tendency to cause it to roll over and thereby producing an excessive burr on the inside edge. The thinner the material the more likely this rolled over burr would increase and, the wider the tape, the more the outside edge would have to stretch causing increased pressures on the inside edge.

II. Rolling Mill (Figure 2)

This technique was used by NASA for fabricating 1/8" wide 0.005" thick 5" inside diameter helical coils and by AMF for producing 50 of the helical coils.

At the conclusion of the 50 coil program, several attempts were made to produce 1/4" wide 0.005" thick 5" inside diameter coils. After several attempts to fabricate a coil with a single thickness of stock, it was decided to use a double thickness by which several turns of the proper dimensions were made.

Because of the results of the first program and the experiments with the 1/4" wide tapes, our proposal was based on the development of a heavier mill to produce the sample coils for this project.

A visit was made to the Fenn Manufacturing Company and discussions were held with Mr. John Charpentier and Mr. M. A. Sperduti. The problem was explained and samples of the 1/8" wide coils were shown. They agreed that the most probable technique to form the coils would be to flat-taper roll them.

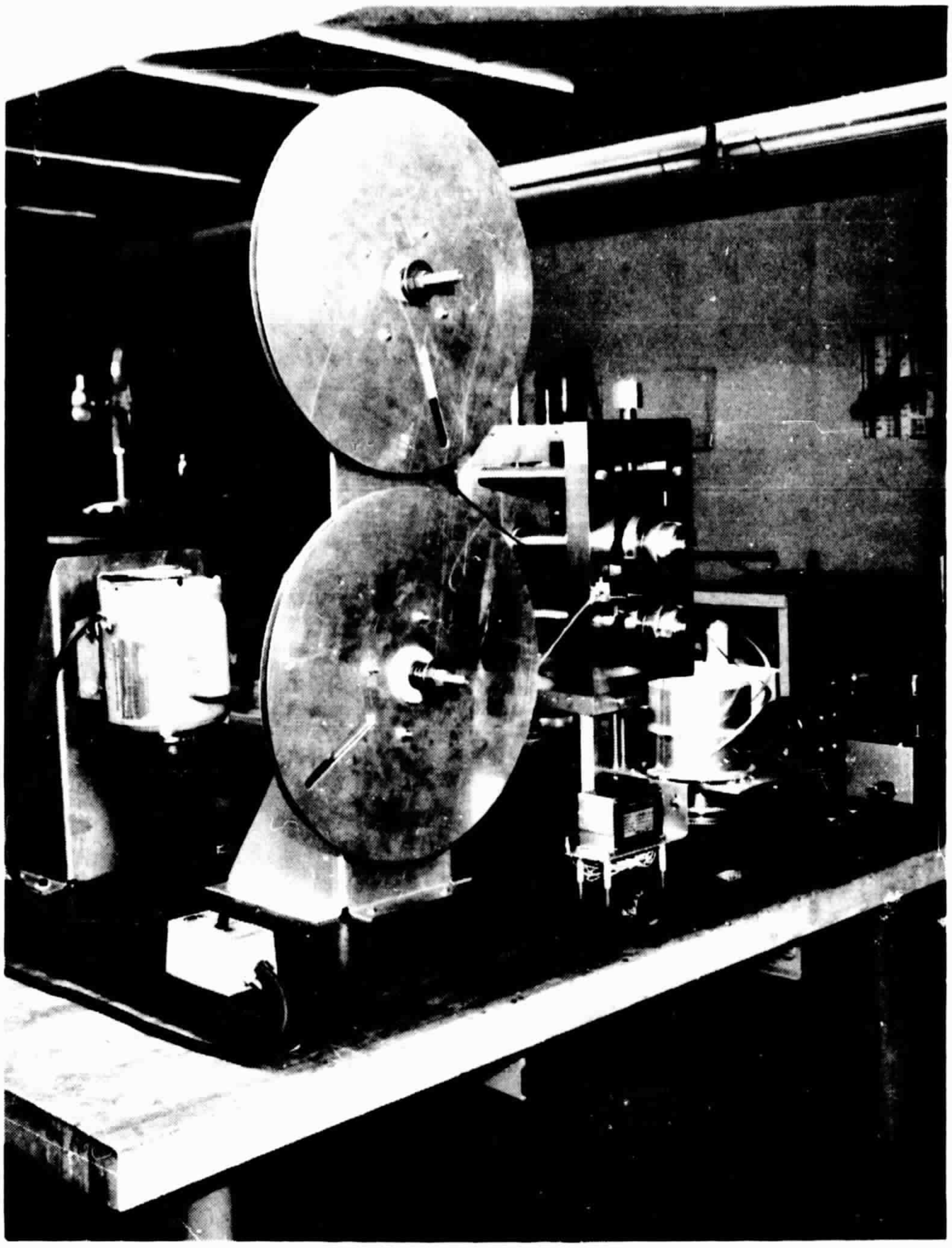


FIGURE 2. ROLLING MILL

As a basis for designing the mill, the formulas from the Fenn brochure were used. This formulas produced values for the pressure between the rolls and the torque and horsepower required to drive both rolls.

III. Other Methods

A. Machining (Figure 3)

Mr. B. H. Kear of the Pratt & Whitney Company who does a lot of experimental work in making flat springs was contacted. All his prototype units are made by machining, and he suggested that this approach to our problem be tried.

A piece of 7075 aluminum round stock (1.898" diameter) with a 1.130" hole drilled through the 3" length was set in a lathe. Eight threads per inch were very carefully turned on the piece until the root diameter reached 1.205". The fins were thinned down by careful shaving until the fin thickness was 0.012". At this point the fins started to bend at the root and work stopped.

This method could be used; however, complex back-up tooling and cutting tools would have to be developed in order to meet the requirements.

B. Casting (Figure 4)

As a second possible method for fabricating the helical coils, centrifugally casting the material into a mold made to resemble two flat springs was investigated. These springs would have steps cut into them .005" and .003" deep. By screwing one spring within the other and clamping them closed within a container, the metal would be centrifugally cast into the grooves.

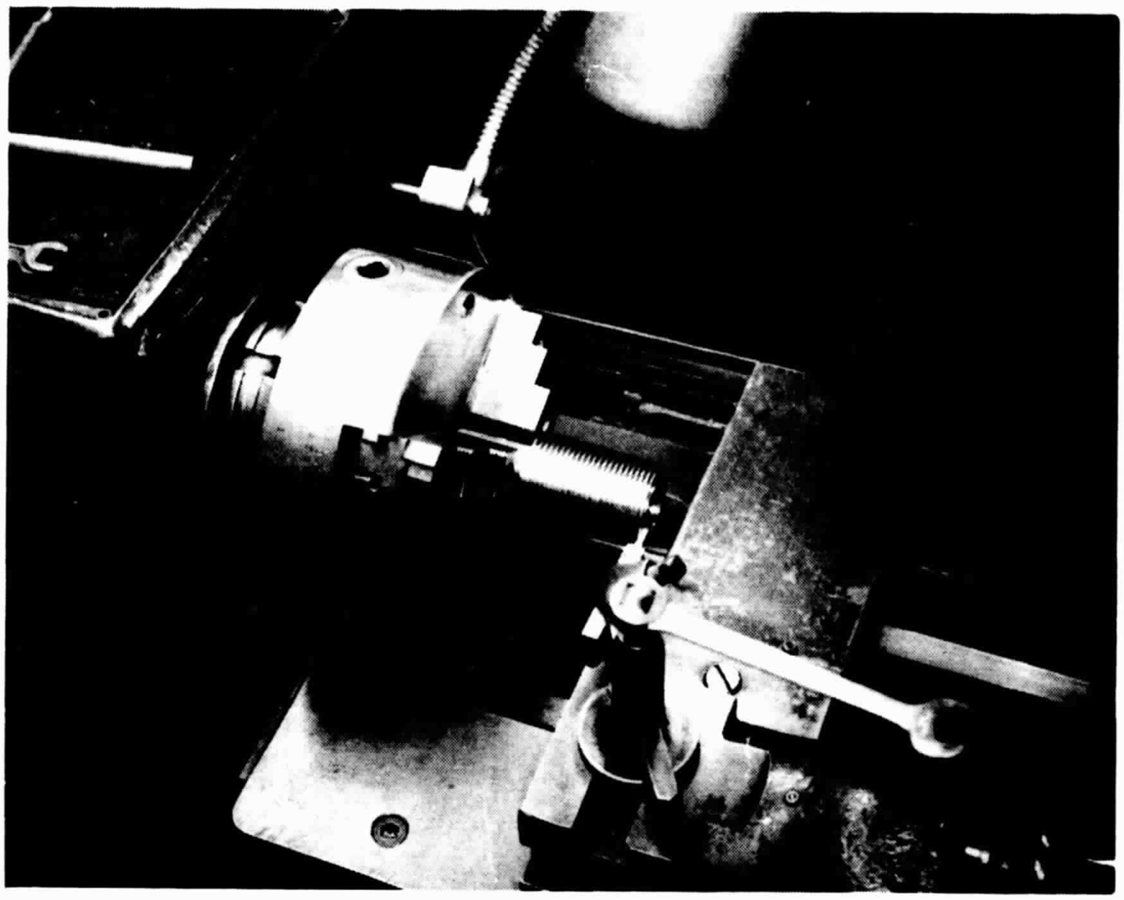
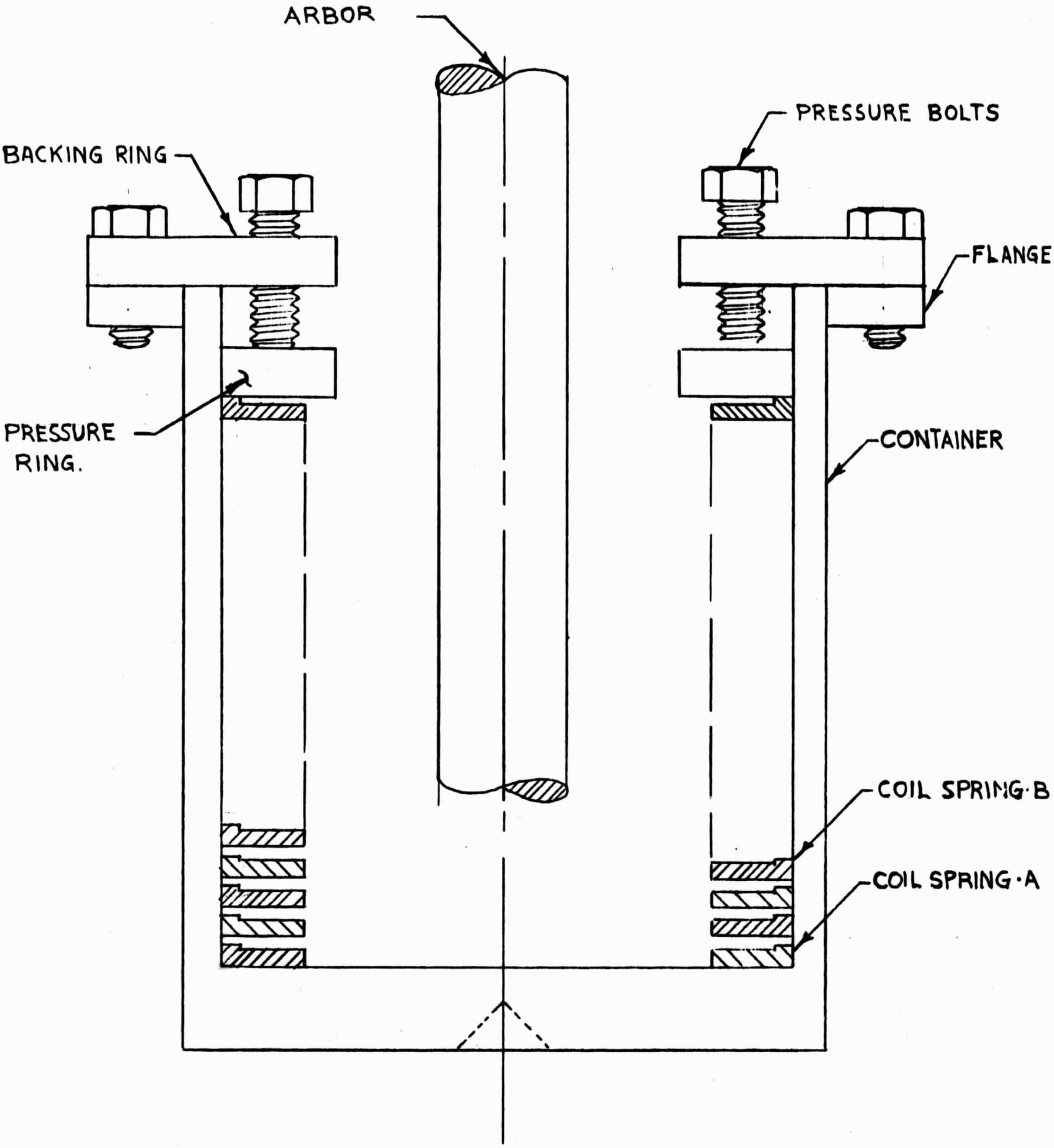


FIGURE 3. MACHINING



CENTRIFUGAL CASTING METHOD

FIGURE - 4

This method could be utilized to make helical coils; however, the preparation of the flat spring type molds would create problems in design and surface finish. Also, it would be difficult to remove the cast helical coils from the molds and removing the flash lines would be next to impossible.

C. Forming (Figure 5)

Some thought was given to the methods used in forming copper bellows. This method consists of placing a thin walled tube into a hydraulic corrugating machine and applying hydraulic pressure internally. As the tube expands outwards into the die, it is simultaneously folded longitudinally, thereby, producing a completely corrugated bellows in one operation.

Another method used to form bellows is roll forming. In this method successive corrugations are formed into the tube wall and by further rolling are deepened and narrowed to the desired configuration.

It was assumed that if these processes could be employed it would be necessary to provide a helix in the hydraulic or mandrel fixture. After the helical bellows were formed the outside and inside diameters could be machined off and two helical coils would be produced. This method would require a tube 30' long wtih a 0.005" wall to produce a 1/2" wide coil with 200 turns. The cost of the tooling to try this technique would be excessive and none of the bellows manufacturers contacted have ever made such a helical bellows.

From these investigations, it was decided that the most practical method for forming a continuous helical coil with 200 turns would be the rolling technique. This decision was based on the fact that work had been previously done

HYDRAULIC FORMING

ROLL FORMING

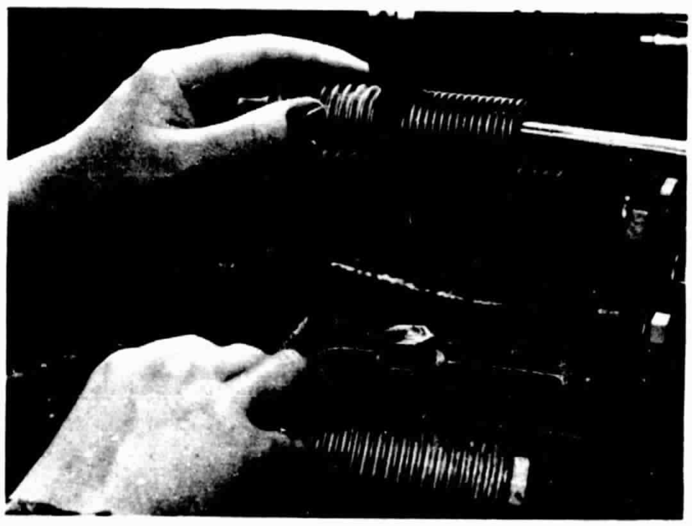


FIGURE 5. FORMING

with this technique, the surface finish could be controlled by the amount of time and effort put into fabrication of the rolls, and it would be much more flexible than the other methods in that minor adjustments could be made while in the middle of a run, and other diameters and widths of coils could be made on the same machine.

C. Machine Development

This phase of the program consisted of the design, fabrication, assembly and testing, and modifications and testing of the rolling mill.

A. Design

Based on the decision to use the rolling mill technique, past development work on the rolling mills used to produce the 1/8" wide, 0.005" thick helical coils was reviewed and applicable changes were made. The design of the rolling mill was developed based on the formulas shown in Figure 6. The basic parts of the rolling mill are shown in Figure 7.

1.) Frame

The main housing for this mill consists of the following parts:

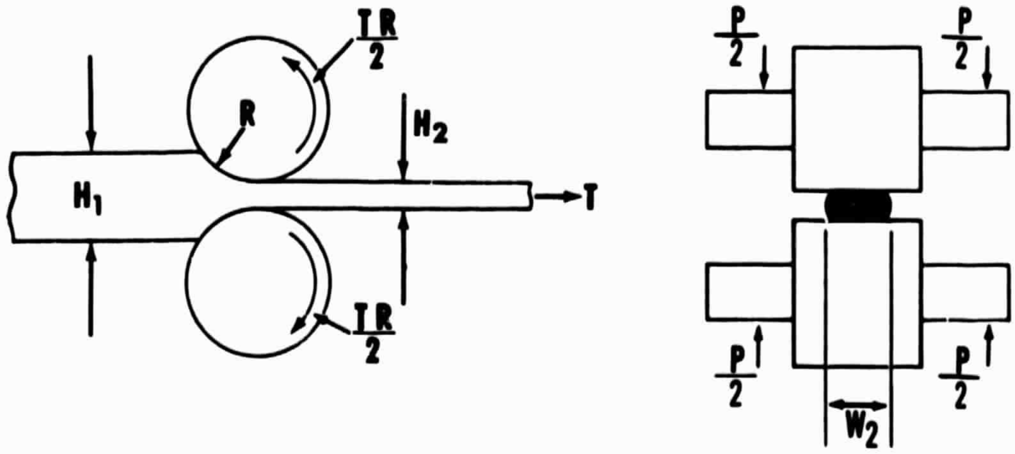
a.) Base plate 1" thick x 8" wide x 15" long steel plate.
b.) Rear bearing frame 1" thick x 8" wide x 11" long steel plate.
c.) Front bearing frame 1-1/2" thick x 8" wide x 11" long steel plate.

2.) Bearing Blocks

a.) Rear bearing block 1" thick x 3-3/8" wide x 5" long.
b.) Front bearing block 1-1/2" thick x 3-1/2" wide x 4-1/2" long.

3.) Bearings

a.) Bottom shaft solid bronze bearings front and rear.
b.) Top shaft solid bronze bearings front and rear, the rear bearing is housed in a self aligning steel bushing.



IF:

P = separating force between upper and lower roll, in pounds;

R = radius of the working roll, in inches;

TR = total torque required to drive both rolls; in inch pounds;

T = tension required to pull wire through rolls which are not driven, in pounds;

HP = horsepower required to drive the rolls at a given speed;

and

h_1 = diameter of entering stock, in inches;

h_2 = thickness of rolled stock, in inches;

w_2 = width of rolled stock, in inches;

(T.S.) = tensile strength of material before rolling, in psi (pounds per square inch);

THEN:

Separating Force =

$$P = f \times 1.5 \times (T.S.) \times w_2 \times \sqrt{R \times (h_1 - h_2)}$$

$$\text{Torque} = TR = f \times 1.5 \times (T.S.) \times w_2 \times R \times (h_1 - h_2)$$

$$\text{Tension} = T = f \times 1.5 \times (T.S.) \times w_2 \times (h_1 - h_2)$$

Horsepower = HP =

$$\frac{f \times 1.5 \times (T.S.) \times w_2 \times (h_1 - h_2) \times \text{feet per minute}}{33{,}000}$$

Where "f" values depend upon the finished width to thickness ratios as follows:

$\frac{w_2}{h_2}$	1.1	1.2	1.3	1.5	1.7	1.9	2.4	2.7	3.0	4.0	6.7	14
f	.21	.29	.35	.39	.43	.46	.50	.55	.60	.62	6.7	.7

Maximum vertical reduction that can be taken without causing roll slippage equals

$$\frac{\text{ROLL DIAMETER}}{40}$$

Minimum practical gage that can be rolled equals

$$\frac{\text{ROLL DIAMETER}}{1000} \quad \text{for steel}$$

down to $\frac{\text{ROLL DIAMETER}}{2000}$ for softer materials

up to $\frac{\text{ROLL DIAMETER}}{300}$ for harder materials

FIGURE 6. CALCULATION FORMULAS

4.) Rolls

a.) Roll diameter 4".
b.) Roll width (work area 11/16".
c.) Roll shafts 13-7/8" long
Front bearing diameter 1-3/4"
Rear bearing diameter 1-3/16"

5.) Drive

Both shafts driven through:

a.) Worm gear: $14\text{-}1/2^{\circ}$ pressure angle
12 Pitch
40 Teeth
3.333 Pitch diameter

b.) Worm: $14\text{-}1/2^{\circ}$ pressure angle
12 Pitch
1.00 Inch pitch diameter

c.) Gear assemblies are right hand and left hand units to drive both rolls.

d.) The worms are driven on a 5/8" diameter shaft connected to an 8" diameter "V" belt pulley.

6.) Motor

a.) Motor: 1/2 HP, 110 volt, 60 cycle, 1725 RPM
b.) Pulley: 2" diameter "V" belt pulley

7.) Roll Speed: 8 feet per minute

D. Calculations

Calculations for the machine were based on the 1/2" wide, .005" thick beryllium alloy 25, 1/4 hard, and are as follows:

1.) Tension. Tension in pounds required to pull strip through rolls which are not driven.

$$T = 1.5 \times (T.S.) \times W_2 \times (h_1 - h_2)$$
$$T = 1.5 \times 81,600 \times .500 \times (.0050 - .0046)$$
$$T = 61,200 \times .0004 = 24.48 \text{ pounds}$$

2.) Separating Force. P = separating force in pounds between upper and lower rolls.

$$P = 1.5 \times (T.S.) \times W_2 \times R \times (.0050 - .0046)$$
$$P = 1.5 \times 81,600 \times .500\ 2 \times .0004$$
$$P = 61,200 \times .0283 = 1,700 \text{ pounds}$$
$$P = 1,700 \text{ pounds}$$

3.) Torque. Total in inch pounds required to drive both rolls.

$$TR = 1.5 \times (T.S.) \times W_2\ R \times (h_1 - h_2)$$
$$TR = 61,200 \times 2 \times .0004$$
$$TR = 48.9 \text{ inch pounds}$$

4.) Horsepower. Horsepower required to move rolls at given speed.

$$HP = \frac{1.5 \times (T.S.) \times W_2 \times (h_1 - h_2)\ s\ fpm}{33,000}$$

$$HP = \frac{61,200 \times .0004 \times 8}{33,000} = \frac{390}{33,000} =$$

$$HP = .0119$$

Based on the above calculations the machine was designed as shown in the attached drawing.

E. Fabrication

The machine was fabricated in AMF's shop, and all the mating surfaces were ground. The rolls and shafts were roughed out and assembled after which the bearing surfaces and roll diameters were ground to size.

The machine was assembled on a baseboard with the motor drive and reels as shown in Figure 8.

F. Testing

When the mill was first operated the problem of picking up chatter marks on the surface finish of the coil arose, later this was found to be due to the bevel gear drive. This problem was eliminated by changing to a worm gear and worm drive.

The mill was set up and tests run to make 1/4" wide coils 5" and 10" inside diameters using a single thickness of slit stock.

These tests resulted in producing coils of the proper inside diameters but the inside edge had ripples or waviness. Adjustments to reduce this effect by varying the angle and pressure to the rolls proved that excessive pressure was being applied to the rolls.

The next approach was to roll using two thicknesses of slit stock and the taper improved to the point that reasonable 10" inside diameter, 1/4" wide, .005" thick coil were produced. After about 75 turns were made the inside diameter dimension changed which proved difficult to wind the coils on the take-up drum. It was discovered that the gear drive assembly had become very hot and as a result heated the rear bearings of both the top and bottom roll shafts which caused the dimension to change. Rolling continued until about 165 turns had been produced, at this time the machine became so hot that it was decided to shut the mill down.

The overheating problem was due to the slight misalignment between the worm and worm gear on the top roll shaft. This was due to the fact that in order to impart the proper taper to the cross-section of the tape to form a coil,

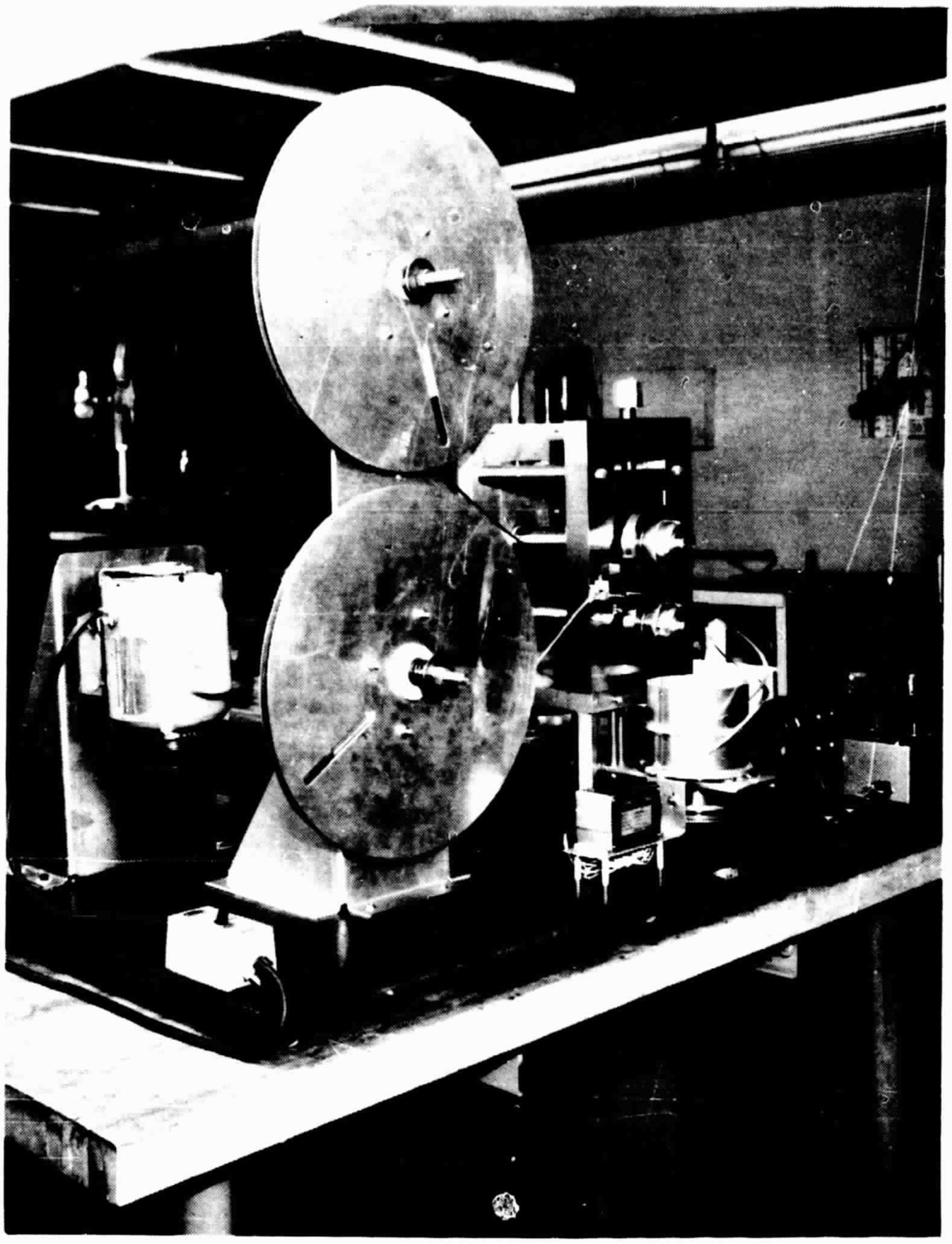


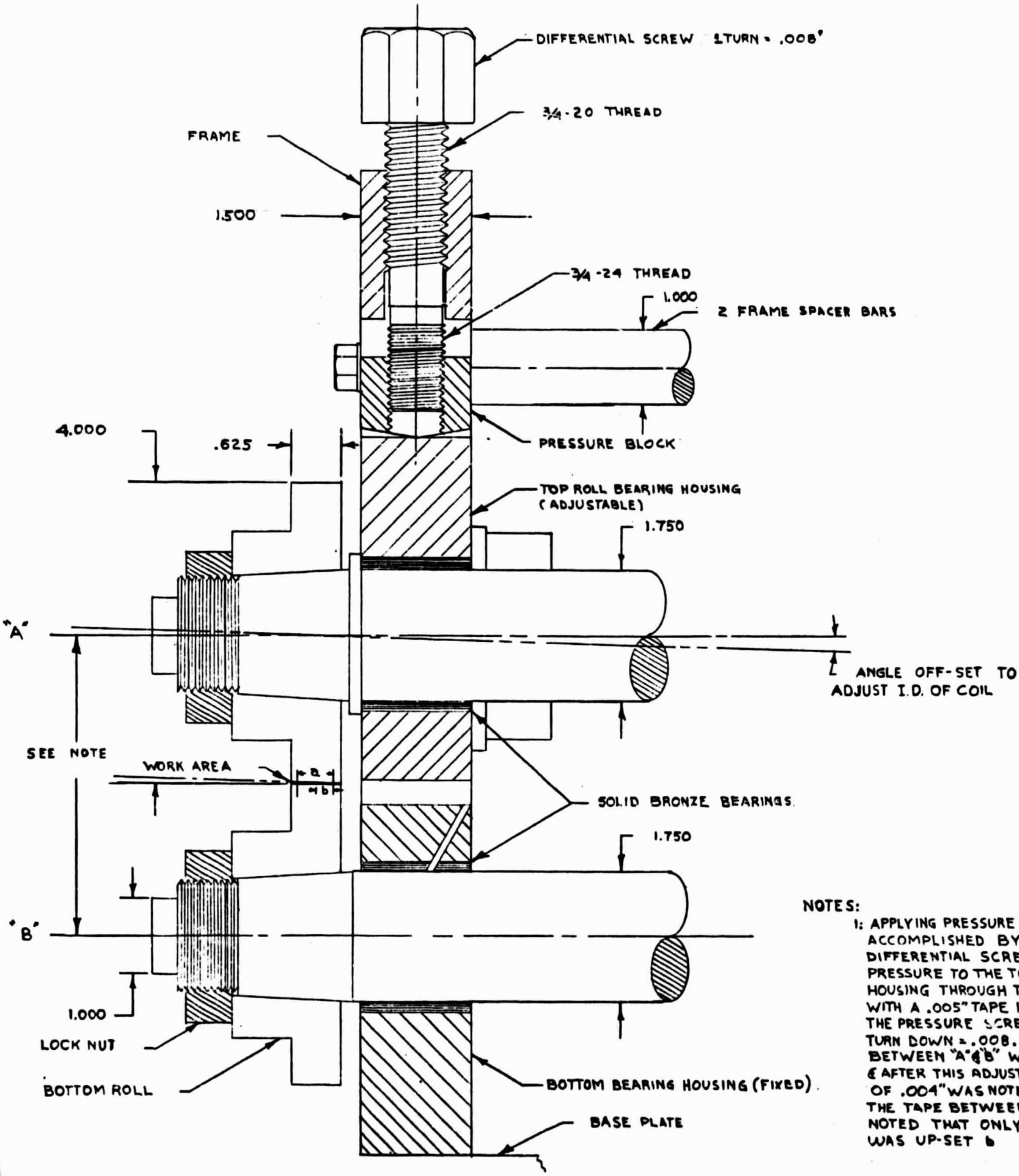
FIGURE 8. MACHINE ASSEMBLY

the rear end of the top roll shaft and bearing housing has to be lowered approximately .026" below the centerline of the top roll; this is turn causes a slight misalignment between the worm gear and the worm as the worm gear is fastened to the rear end of the top roll shaft. In order to compensate for this misalignment the worm gear and worm were taped together, setting the angle into the top shaft gradually until the off center drop was 0.050".

The machine was again set up to produce a 5" inside diameter, 1/4" wide, .005" thick coils. This required a slight increase in the angle and higher pressure on the front pressure screw. Double thicknesses of tapes had to be employed to get the inside diameters desired. In this test program we were able to produce 1/4" wide coils, 5" and 10" inside diameter and .003" and .005" thick.

The next attempt was to produce coils 1/2" wide with .005" thickness. Attempts were made using a single thickness of tape. The angle and pressures were varied with the same results. The waviness on the inside edge was an indication that the pressure between the rolls was not evenly distributed across the width of the tape. Increasing the pressure would provide a good coil; however, it was impossible to get consistent coils of the same diameter.

The next attempt was made using two thicknesses of .005" thick tape. This proved to be more successful but required excessive pressures between the rolls in order to get the 10" inside diameters with no waviness on the inside edge of the coil. Again it was difficult to get consistently concentric coils. A check



NOTES:

1: APPLYING PRESSURE TO THE ROLLS IS ACCOMPLISHED BY TURNING THE DIFFERENTIAL SCREW WHICH APPLIES PRESSURE TO THE TOP ROLL BEARING HOUSING THROUGH THE PRESSURE BLOCK. WITH A .005" TAPE IN THE WORK AREA (a) THE PRESSURE SCREW WAS TURNE 1 FULL TURN DOWN = .008. THE DISTANCE BETWEEN "A" & "B" WAS MEASURED BEFORE & AFTER THIS ADJUSTMEND & AN INCREASE OF .004" WAS NOTED AND ON INSPECTING THE TAPE BETWEEN THE ROLLS IT WAS NOTED THAT ONLY HALF THE TAPE WIDTH WAS UP-SET b

FIGURE - 9

was made on the cantilevered end of the shafts as shown in Figure 9. By setting the shafts parallel, and taking one full turn on the pressure screw, (a differential screw with one turn is equal to .008" movement) the distance between the two ends of these shafts was measured. It was determined that the top shaft was deflecting .002" upwards and the bottom shaft was deflecting .002" downwards and that the rolls were making a .001" depression in the tape only across 1/2 the width of the 1/2" wide tape. It was concluded from this the force calculated to roll the coils was inaccurate. A review of the design calculations were made and from all indications they were correct. The pressure applied to the rolls through the differential pressure screw was again calculated, and found to be approximately 12,000 to 15,000 pounds assuming 50% efficiency due to friction losses. Because this figure was relatively high, the force required to bend the 1-3/4" diameter shaft with a moment arm of 1.250" (calculated from center of bearing to center of strip) was calculated and found to be 30,000 pounds. This number would increase if the moment arm was shorter.

To prove out the calculations, 1/2" wide strips of .030" thick aluminum, .018" stainless steel, and .015" beryllium copper were sheared and the mill set at the proper angle with approximately one half turn on our pressure screw (.004"). With this setting several coils with 8" inside diameter and 6" inside diameters were run off with no problems. Four (4) thicknesses of the .005" slit stock were tried, a 10" diameter coil was fabricated. This required a 1-1/2 turn on the pressure screw equal to .012" movement. A slight waviness appeared on the inside diameter and it appeared that there was some slippage between the layers of tape. The machine was not working smoothly and appeared to be overloaded.

Another test was run with .003" thick slit stock and the results were worse than with the .005" thick stock. Runs were made with 1, 2, 3, and 4 thicknesses of material and all had a waviness on the inside edge of the coil. This waviness indicates that the pressure is not being applied evenly across the 1/2" width of the tape. Increasing the pressure on the pressure screw helps to reduce the waviness; however, it is impossible to apply any more pressure to eliminate this effect due to the deflection of the roll shafts.

G. Conclusions

As a result of the above tests and modifications to the rolling mill produced for this program, it was felt that the feasibility of this technique has been demonstrated. However, the tremendous pressure differences that are involved in the rolling of .015" thick stock and .003" to .005" thick stock,is very puzzling.

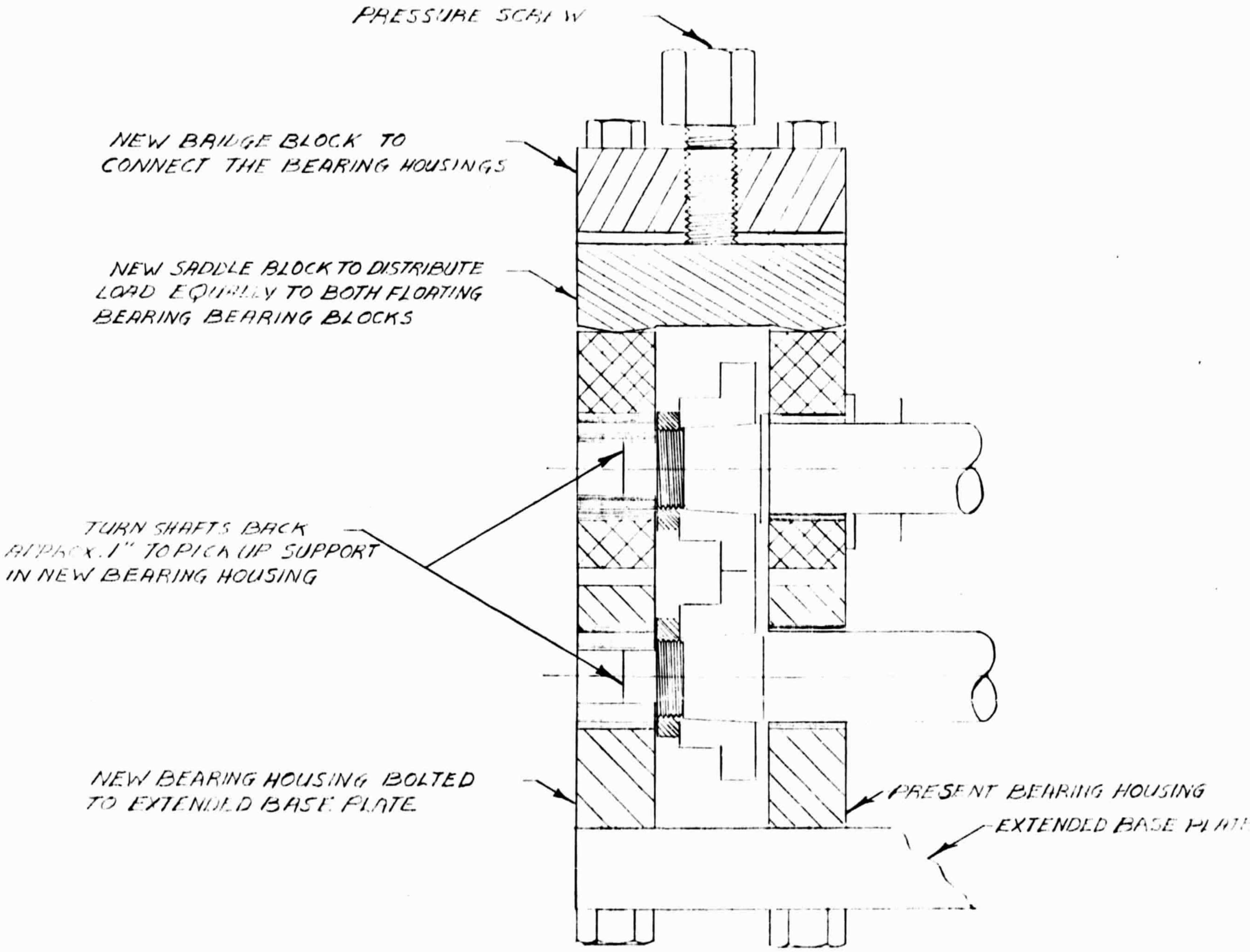
In order to accomplish the desired end products, the following modifications are recommended:

1.) Gear Drive

The gear drive would be mounted on a separate plate and the two roll shafts driven through two universal drive shafts. This would eliminate any misalignment between the worm and worm gear and it would also eliminate any heat transfer into the bearing housings causing a dimensional change.

2.) <u>Rolls</u>

An additional bearing support would be provided on the outboard end of the roll shafts. This would eliminate any deflection of the two roll shafts on the cantilevered section. Equal pressure could then be applied across the width of the tape through a centered pressure screw that would evenly distribute the load to both bearing housings (See Figure 10.)



ROLLING MILL MODIFICATIONS
FIGURE-10