A COMPARISON OF FIVE WHEAT THRESHABILITY PARAMETERS USING AN INSTRUMENTED LABORATORY CYLINDER

by

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INTRODUCTION

The advantages of testing the combine performance right in the field can not be denied. Routine tests are run on a particular machine to know how it will perform when operated under certain crop conditions, and what adjustments (if any) are required to obtain satisfactory performance.

The kernel losses in the past and even at present are regarded as a basic criteria of combine performance. The losses occur at different places in the combine and each loss is a measure of the performance of a combine component under given conditions. To find these losses provisions are made for a simultaneous collection of the material discharged from the straw rack, the material from the shoe and/or seed at the grain tank. All the collections are made in canvas bags while the machine is operating at a constant speed and under near steady state conditions. Separate collections from the rack and shoe are made. The material collected in the top bag which is held just under the rack, consists of straw, threshed seed (rack loss), and some of the unthreshed seed. The percentage of the unthreshed material which is known as the cylinder loss is a measure of threshing performance (the losses are represented as the percentage of the total weight of the threshed material passing through during a particular run). The characteristic grain loss curves can be obtained from these tests. Since the losses at different places in a combine are greatly affected by the crop condition, sufficient amount of data with a wide variety of crop conditions is therefore required before the results can be generalized.

The above procedures are tedious and time consuming. These tests are relatively easy to carry out where constant weather conditions prevail over a long period of time, but such conditions are not common. Moreover costs to maintain a trained staff for carrying out experiments in all areas is most of the time not possible. Therefore there is a need for a procedure from which a quick assessment of the overall performance of different machines can be made. As the same combine is required to thresh different crops and under a wide range of conditions, it is therefore necessary to set a base line which will describe the combine performance.

Threshing is probably the key operation in combine performance. Cylinder loss is therefore of prime importance. The cylinder loss consists of all the unthreshed grains left in the heads and carried over the straw rack. It does not include any loose kernels or grains. This source of loss is important because it is one of the major losses in the combine. It is also important due to its effect on rack and shoe losses. It is not efficient to minimize cylinder loss without considering the other losses. Almost all of the kernels can be knocked out of the heads by adjusting cylinder speed and clearances, but undoubtedly the other losses will go up in doing so. Rack loss consists of shelled or loose grain carried over the rack with the straw. It is also a key loss and in most cases is a criterion to predict the shoe loss. The rack loss depends upon the cylinder adjustments and the rate of threshing. Shoe loss consists of all the loose grain together with the chaff which is carried over the cleaning shoe. Like rack loss this loss also depends upon threshing operation. If the straw is broken quite badly in the cylinder, the small pieces of straw will sift through the rack making the separation more difficult. This loss affects the combine performance to a great extent.

REVIEW OF LITERATURE

Threshing of small grains has received much attention by many researchers during past several decades. However the threshing principles applied many years ago are not different from present day techniques. In principal, introducing the grain between the concave and cylinder is the same as applying force to grain on a threshing floor.

Lamp and Buchele [1960] defined threshing action as, the force applied on the grain in such a manner that the applied force exceeds the forces which restrain it. Long [1951] defined threshing as the ease with which the grain can be separated from the florets.

There are three general methods of threshing grain as stated by Lamp, a) mechanical method applied such as rubbing and stripping; b) impact or impulsive acceleration, as occurs when a cylinder bar strikes unthreshed grain; c) and by a non-impulsive acceleration which would result if a head of grain were suddenly accelerated. Cylinder-concave threshing is accomplished principally by the use of the first two methods.

Delong & Schwantes [1942], however, did not agree that the cylinder threshing process is totally the resultant of rubbing action as in the burr mill. They considered the threshing action as the resultant of the impact produced by the fast moving parts on the grain or the forces produced by the fast moving crop material which comes in contact with the slower moving or relatively stationary parts.

According to Lamp [1960], centrifugal force is the major factor affecting threshability. Lamp's statement was, however, contradicted later by the work performed by Buchanan [1964] who concluded from his results that threshing is mainly due to factors other than centrifugal force.

Several researchers reported the weather conditions to be a significant factor affecting combine threshing performance. Long [1951] noted that relative humidity of the air plays an important part in threshing efficiency. Johnson [1959] reported that seasonal differences are significant even though working with the same variety and machine. He suggested that in efficiency studies it is important to determine the straw moisture content, especially during the rewetting and drying period. Johnson further indicated that, during normal combining period, the straw is at a lower moisture content than the grain; however, for early morning and late evening combining this does not hold true and may cause a change in performance. Earlier work by Delong and Schwantes [1942] provides similar results when combining barley.

It is an established fact that certain grain varieties thresh easier than the others. For the normal threshing the combine must be adjusted for different varieties, even though the moisture content of the varieties remain constant.

Silver, [1942] when studying the stubble height effect on efficiency of combining, found that Trumbull wheat seemed to be the hardest to shell, as the cylinder loss in this variety was slightly higher than in other varieties. Throne variety showed the lowest cylinder loss.

According to Bigsby [1959] 20 to 25 percent more cylinder power was needed to thresh solid stemmed varieties of wheat (compared to hollow stemmed varieties at the same feed rate). Two possible reasons for this difference were given: There is more straw for a given amount of grain in solid stemmed variety. However, the ratio between straw and unthreshed material indicated that difference in weight was not great enough to account for this difference. The other possible reason was that more power was absorbed in crushing the straw in solid stemmed varieties. The later assumption was supported by the fact that there were higher and more frequent peaks of the torque traces in threshing the solid stemmed variety.

The cylinder speed and cylinder to concave clearances adjustments are used to obtain the desired threshing results during combining. Delong and Schwantes [1942] suggested that if a minor change in threshing is required, small changes in either the cylinder speed or cylinder to concave clearance will give the desired results, but to obtain a major change both the cylinder speed and clearance need adjustment.

Experiments performed by Park [1954] on clover showed the effect of using different types of cylinders. Total unthreshed seed losses were as high as 40 percent. A slight improvement in the results was obtained when an angle bar cylinder was used. Arnold [1964] observed an increase in power requirement with an increase in concave length.

Johnson [1959] reported an increase in cylinder loss with an increase in grain moisture content for any specified cylinder and concave settings. Johnson stated that this loss, under normal harvesting conditions, can be kept well below one percent by using appropriate cylinder and concave adjustments.

Lalor and Buchele [1963] reported that 60 to 80 percent of the grain is separated from the straw in the threshing cylinder. Kolganov [1952] performed experiments on a multistage cylinder and found that the highest quality grain is threshed in the first stage at lower cylinder speeds, the remaining grain was obtained at normal cylinder speeds in second stage.

Lamp [1960] in his study on centrifugal threshing of wheat found that under normal conditions a centrifugal force of 0.2 lbs was sufficient to obtain 98% of the grain and that this force can be reduced up to 50% if the force is applied in such a manner that it bends the rachilla. Buchanan and Johnson [1964] later reported that if a centrifugal force of 0.3 lbs is applied, 98% of the threshed grain can be obtained independent of the method of holding the heads.

In testing the effect of holding the heads in centrifugal threshing, Lamp and Buchele [1960] found that twice as much force was needed in reverse than in regular mounting. Regular mounting was referred to as heads extending on radial lines from center and constrained by holding the straw. This difference in force was not as great for low moisture contents. Threshing achieved was never above 50% for intermediate holdings. They said in the case of reverse mounting the kernels rotate about their attachment, the rachilla is sheared and the glumes open during the process.

An inverse relationship was observed by Long [1951] between the percent of seed threshed and the moisture contents of the sample. He concluded that threshability was susceptable to changes in the moisture content between 10 to 18%, but an insigificant effect was noted when moisture content decreased from 9 to 6%.

Miles [1956] reported a decrease in corn yield for both higher and lower grain moisture contents. Lamp and Buchele [1960] found that higher moisture contents required larger threshing forces for wheat. Nearly twice as much force was required for 98% threshing at 29% kernel moisture than was required for threshing oven-dry wheat.

Certain other crop properties are also important in considering the threshing operation. The stiffness of the straw was considered important by Silver [1942], both from the standpoint of cutter bar losses and threshing. He inferred that the variety with a stiff straw will not be broken up as much by the cylinder. Therefore the grain will sift more quickly, decreasing the rack loss.

Arnold [1964] reported an increase in power requirement with a decrease in moisture content. He referred this effect to low coefficient of friction which causes a reduced grip of the cylinder and hence give rise to more pressure requirement to get the material through the drum.

INVESTIGATION

Research Objectives

1. To develop some quantitative measure of crop threshability parameters (threshing indices).
2. To see which of these indices (if any) are more sensitive to the variables under study and are better representative of crop threshability parameters.

Materials and Equipment

A threshing unit was designed to achieve a new system of measuring threshability parameters and thus in turn predicting the combine performance.

The threshing unit (Drawing 1 & 2 Appendix B) consisted of 12 in. cylinder, which was made out of two aluminum discs (1)* to keep the inertia as low as possible. Conventional rasp bars (2) about 7 - 1/4 in. in length were mounted on the discs. The cylinder was keyed at point A to the 1 in. shaft (3). The shaft was supported at either end by a four-bolt flange bearing (4), mounted on a 6 in. x 8 in. plate (5). At each end on the inside of the plates, four linear ball bearings (6) were mounted so that 1/2 in. 60-case shafts (one at the top (7) and the other on the bottom (8)) could pass through respective pairs of linear bearings freely. The 60-case shafts were supported by 1/2 in. support blocks (9), and the blocks were in turn mounted on the 7 in. x 10 in. plates (10). These plates were attached to frames which were restrained by the horizontal & vertical adjustment screws (11).

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*Number in parentheses (in this section only) refer to part numbers in the appended drawings, Appendix B.

A combination of plates (5), linear bearings (6), 60-case shafts (7&8), support blocks (9), frame and adjustment screws (11) provided a complete and precise adjustment of the cylinder in the horizontal plane.

A similar combination of plates (10), linear bearings (13), 60-case shafts, support blocks (12), frame and adjustment screws (11) provided the complete adjustment in the vertical plane. The support blocks (12) were mounted on 3/16 in. thick support plates. The independent adjustments in the horizontal and vertical planes provided capability to maintain both front and back clearances, between cylinder and concave. The cylinder was powered by a 3 hp. capacitor start motor via a variable speed V-belt drive. A beater-bar assembly (14) was provided to prevent material recirculation. Threshed material is collected in a perforated box (16) mounted at the back end of the threshing unit. The beater was integrally mounted with the cylinder.

A concave of open construction type with a radius 3/16 in. larger than the cylinder and about 130° was chosen for the experiment. The details of construction are shown in Drawing 2, Appendix B. The concave was divided into six parts by fastening sheet metal divider plates along the concave length. A tray (15) was also likewise divided to obtain the threshed as well as unthreshed material as deposited in respective areas along the length of the concave.

A belt conveyor unit was designed to deliver material stream to the cylinder. Provisions were also made to feed the crop radially and at an angle of about 30° with the horizontal. The conveyor was driven by a separate 1/2 hp. A.C. motor. A suitable combination of pullies and gear reducer gave a belt speed of about 35 fpm.

The conveyor unit consisted of head and tail pullies (17 & 18), which were mounted on 3/4 in. two-bolt flange and take-up (19 & 20) bearings respectively. A rubber belt was used. The surface of the belt consisted of parallel, transverse, inverted V-ridges, thus assuring a positive grip of the crop material spread.

Torque-meter

The torque was measured on the main cylinder shaft. To get an increased amount of elastic deflection, a reduced 1/4 in. tool steel square section was used. Details of torque-meter design are shown in Fig. 1. The square section was cut from a square tool steel. Square holes were broached in sections A & B to accommodate the square section. The parts were then welded together.

A two inch tube was slipped over the main shaft. One end of the tube was attached to the shaft by means of a key and allen screws. The other end was centered and constrained to angular movements by means of a pair of aircraft bearings. On the free end of the tube two slots (1/2 in. x 1/2 in.) diametrically opposite to each other were also provided. These slots limited the angular deflection of the square section. For torques above 50 in.-lbs. a 1/4 in. pin attached to the main shaft through the shaft contacted the slotted free end of the tube, causing the transfer of torque through the tube rather than the square section. This arrangement protected the reduced square section from permanent deformation caused by starting torques of the power motor or other shock loads.

Torque Sensing, Amplification and Recording System

The strain gage bridge configuration and location of gages on square section is shown in Fig. 2. The arrangement requires an accurate gage

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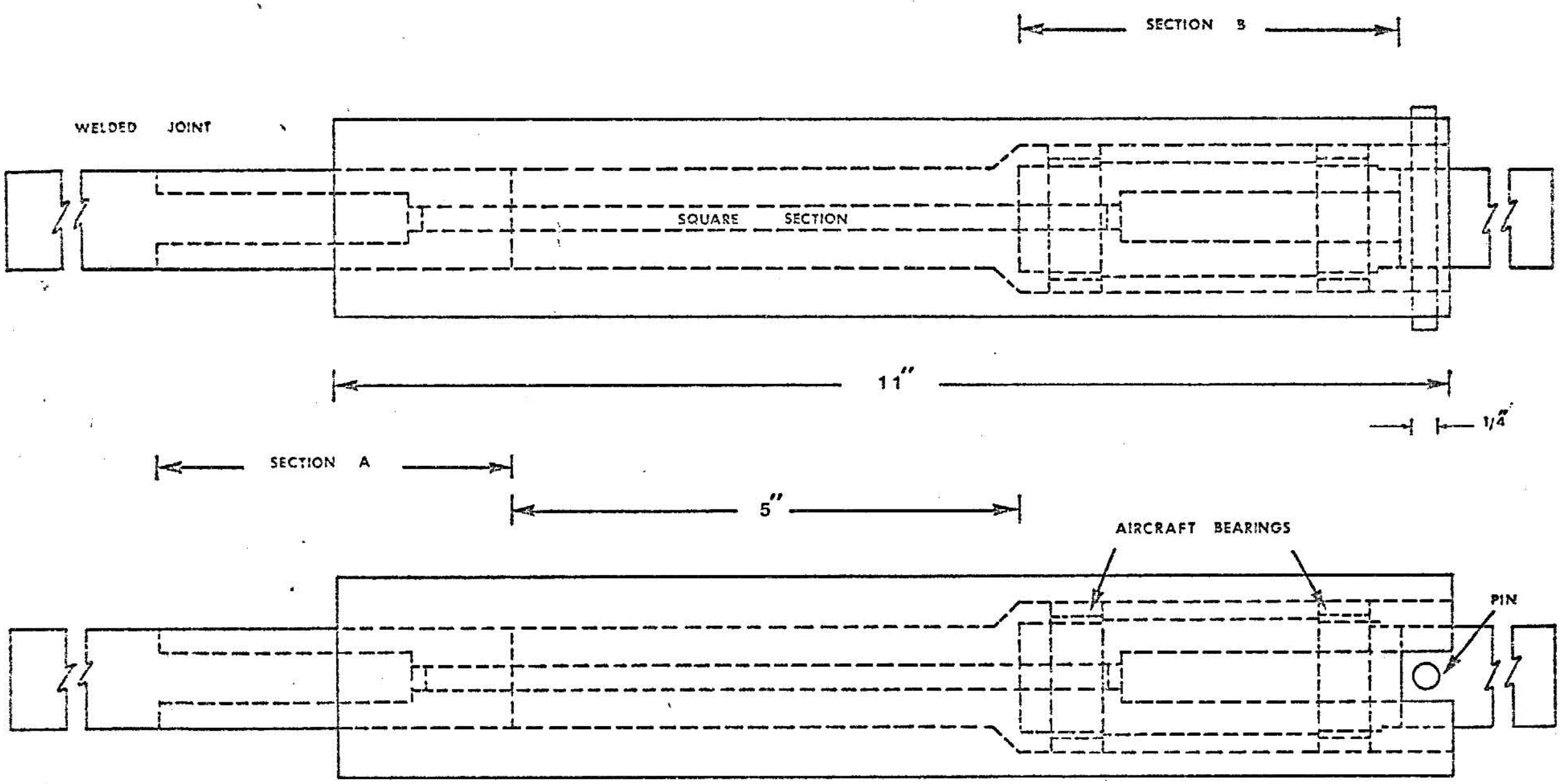

FIG. I. Torque-meter design details.

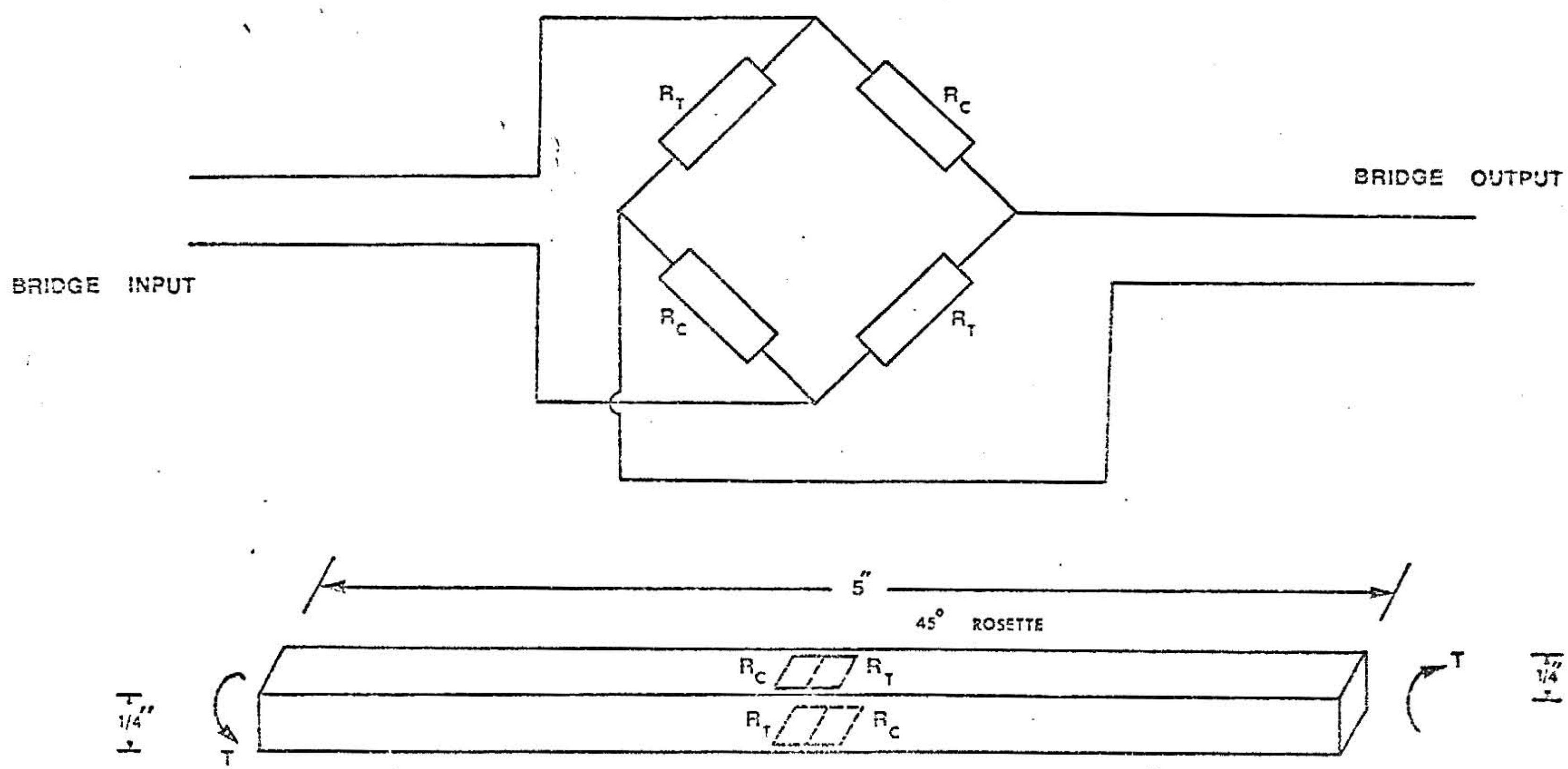

FIG. 2. Strain gage location and wiring diagram used for sensing torque on the main cylinder shaft.

placement at 45° with the shaft axis with the tension and compression gages diametrically opposite each other (thus canceling strain due to bending forces).

Gage placement was facilitated by using two 45° rosettes. Since the corners of a square shaft under torsion are stress free, solder joints between lead wires and gages were located on the corners of the shaft. These joints are often a source of fatigue failure if located in a high stress region.

The main cylinder shaft was provided with 1/8 in. pilot hole, to bring the strain gage connections to the slip ring unit (Drawing 1, Appendix B). The output from the bridge was filtered and then fed to an amplifier-oscillograph recording system.

Calibration

The torque meter was then statically calibrated over the expected range of operation, by keeping all the interfering inputs at one constant value. The torque on the shaft was changed by replacing different weights on the arm attached at the threshing cylinder.

A single least square line was fitted to the plotted points. It was noted that there was more deviation of data points from the fitted line in the range of 0 to 10 and 38 to 48 in.-lbs of torque conditions.

A better fit was obtained by fitting two lines to the data, Fig. 3, one in the range of 0 to 24 and the other over the range of 24 to 48 in.-lbs (equation 1 and 2, respectively). A method outlined by Doeblin (1966) was followed for the derivation of these equations. A reduction of about 15 percent in the deviation of the data points from its respective fitted line was obtained. The relation between the cylinder torque (in.-lbs)

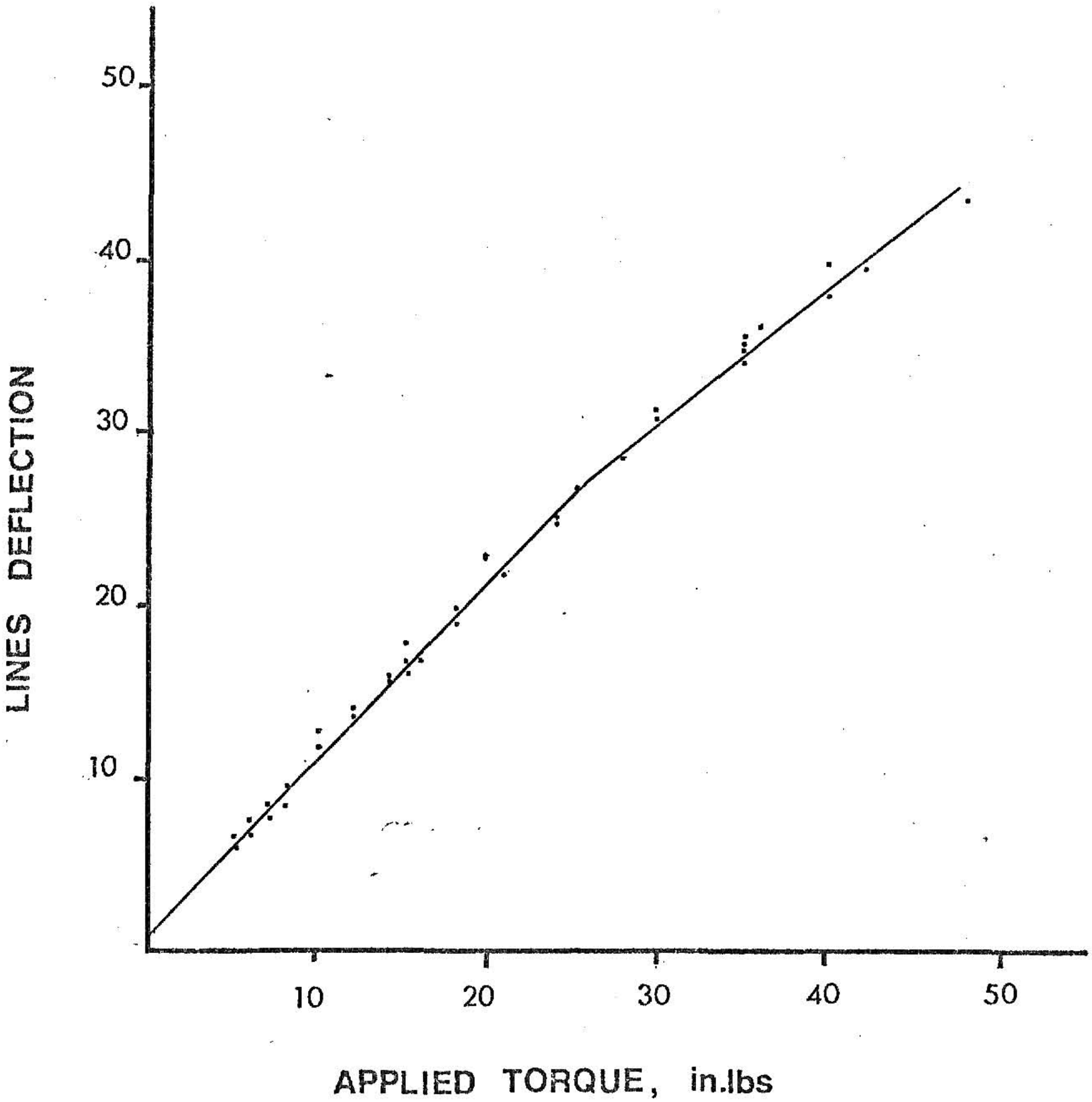

FIG. 3. Calibration curve for the torque-meter.

and recorder chart line deflections are given by the following least square equations

$$Q_i = \frac{Q_o - 1.2868}{1.0246} \tag{1}$$

$$Q_i = \frac{Q_o - 6.9651}{0.7889} \tag{2}$$

where

Q_o = number of lines deflection from zero on recorder chart (output quantity)

Q_i = true torque, in-lbs (input quantity)

The values of Q_i can be computed from above equations for given Q_o. The computed values are free of bias. Since the least square equations are derived from scattered data points the computed values must have some $\pm$ error limits to compensate for imprecision (random error). Error limits can be obtained by calculating standard deviation of Q_i (SQ_i). Assuming a normal distribution and the 99.7 percent limits ($\pm 3S_{Q_i}$) error limits are $\pm$ 0.6242 and $\pm$ 0.2436 in-lbs for equations 1 and 2, respectively.

Experimental Material

Thirteen wheat varieties which were used in this experiment were grown at the Experimental farms, Dept. of Agronomy, Kansas State University. The bundles were made and brought to the laboratory where infested, immature, and relatively smaller heads were separated from the rest, to assure a more uniform sample. Eighty bunches, each containing twenty heads were made. The material was left under room conditions for a week and was later stored in sealed cans.

Preliminary Tests

Two machine parameters, cylinder speed and cylinder to concave clearance, were chosen to determine their effect on threshability. Several threshability indices were defined, a brief description of each is given below.

The concave in this study was divided into six compartments along the length. It was expected that material received in each compartment would differ from variety to variety and also due to combination of cylinder speed and concave clearance in use. For example, easier to thresh varieties would deposit more material in first few compartments than the varieties which are harder to thresh. Similarly harder to thresh varieties would also result in more unthreshed material and vice versa.

Characteristics of the torque-time curves obtained at the threshing cylinder were also considered as threshability parameters. With a change in machine parameters or the amount of material fed it was possible to change the shape of the torque-time curve. Harder-to-thresh varieties would result in higher peaks and a gradual decay; easy threshing varieties would result in lower peaks and an exponential decay. Due to above reasons area, span and height of the torque-time curve were considered as three indices of interest.

During the preliminary tests the level of each factor under study was decided. Sample size was changed and its effect upon the torque-time curve was observed. It was noted that 60 heads provided an adequate response from the torque meter for all different varieties in use. It was also noted that regardless of wheat variety, close concave clearance (mean clearance of 1/8 in.) and the highest speeds obtainable (1740 rpm); the threshed material was well distributed in the concave compartments. On this basis the clearances generally used during harvesting were selected. The levels of the factors under study are given in Table 1.

TABLE 1. Level(s) of the Variables Used in Threshing Experiment

No.	Variables	Range
1.	Feed rate	60 heads/run
2.	Conveyor belt speed	35 ft/min.
3.	Cylinder speed	1360, 1480 rpm.
4.	Cylinder to concave clearance	3/16, 5/16, 7/16 in.

Method of Procedure

For each test three bunches of individual wheat sample, (each bunch containing twenty heads) were taken from the stored sample. The straw length was reduced to 9 in. and weight was recorded. The material was put on the trough by raising the belt conveyor (Drawing 2 Appendix B). After the check for the cylinder speed and clearance were made, material was ready for feeding. During threshing, torque-time curves were also recorded. After threshing, the number of threshed as well as unthreshed kernels in each compartment were recorded. All the tests were replicated twice. A complete set of results is shown in Appendix A.

RESULTS AND DISCUSSION

Six tests were performed on each of the thirteen varieties (2 speeds and 3 cylinder-to-concave clearance). The six tests were assigned randomly. Each test was replicated twice. For a particular test all the thirteen varieties were run before a change in speed or cylinder-to-concave setting was made. This type of orderly arrangement made the experiment a split-split plot design. Since it was desired to investigate the effect of the variables under study, an analysis of variance was performed on the threshed and unthreshed kernels (count and percentage basis) obtained in different compartments along the concave. Analysis of variance was also performed on maximum torque, area under the torque-time curve and span of the torque-time curves, which were obtained at the main cylinder shaft.

Two different models were used. First model was used for analyzing threshed and unthreshed data (count and percentage basis), while the other model was used for analyzing torque-time curve data and for the total unthreshed material (percentage basis). The description of the models is given below.

Model 1.

$$
\begin{aligned}
PRTH_{ijk\ell m},\ UN_{ijk\ell m},\ TH_{ijk\ell m} = {} & R_i + S_j + C_k + R_iS_j + R_iC_k + S_jC_k \\
& + R_iS_jC_k + V_\ell + R_iV_\ell + S_jV_\ell + C_kV_\ell \\
& + R_iS_jV_\ell + R_iC_kV_\ell + S_jC_kV_\ell + R_iS_jC_kV_\ell \\
& + P_m + S_jP_m + C_kP_m + V_\ell P_m + S_jC_kP_m \\
& + S_jV_\ell P_m + C_kV_\ell P_m + S_iC_jV_\ell P_m + E_{ijk\ell m}\ .
\end{aligned}
$$

Where,

$PRTH_{ijk\ell m}$ = Threshed material (percentage basis) for the i th replication, j th speed, k th clearance, ℓ th variety and m th position.

$TH_{ijk\ell m}$ = Threshed material (count basis) for the i th replication, j th speed, k th clearance, ℓ th variety and m th position.

$UN_{ijk\ell m}$ = Unthreshed material (count basis) for the i th replication, j th speed, k th clearance, ℓ th variety and m th position.

R_i, S_j, C_k, V_ℓ, and P_m = are the average true effects due to i th replication, j th speed, k th clearance, ℓ th variety and m th position.

R_iS_j, R_iC_k, S_jC_k, R_iV_ℓ, S_jV_ℓ, C_kV_ℓ, S_jP_m, C_kP_m, $V_\ell P_m$, are possible two-way interaction effects due to i th replication, j th speed, k th clearance, ℓ th variety and m th position.

$R_iS_jC_k$, $R_iS_jV_\ell$, $R_iC_kV_\ell$, $S_jC_kV_\ell$, $S_jC_kP_m$, $C_kV_\ell P_m$, $S_jV_\ell P_m$ = are the possible three-way interaction effects due to i th replication, j th speed, k th clearance, ℓ th variety and m th position.

$R_iS_jC_kV_\ell$, $S_jC_kV_\ell P_m$ = are four-way interaction effects for i th replication, j th speed, k th clearance, ℓ th variety, and m th position.

$E_{ijk\ell m}$ is the random error of observations due to i th replication, j th speed, k th clearance, ℓ th variety, and m th position.

Model 2.

$$TOTUN_{ijk\ell}, SPAN_{ijk\ell}, PEAK_{ijk\ell}, AREA_{ijk\ell} = R_i + S_j + C_k + R_iS_j + R_iC_k + S_jC_k + R_iS_jC_k + V_\ell + S_jV_\ell + C_kV_\ell + S_jC_kV_\ell + E_{ijk\ell} .$$

Where,

$TOTUN_{ijk\ell}$ = is the total unthreshed material (percentage basis) due to i th replication, j th speed, k th clearance and ℓ th variety.

$SPAN_{ijk\ell}$, $PEAK_{ijk\ell}$, $AREA_{ijk\ell}$ are the span, maximum torque and area under the torque-time curve due to i th replication, j th speed, k th clearance and ℓ th variety.

The description of the terms used on the right hand side of the model 2 are the same as for model 1.

Analysis of variances was performed for two replications via AARDVARK, a canned statistical program. The results are shown in Tables 2 & 3. In Table 2-A, 2-B, and 2-C and in Tables 2-D and 3 three and two error mean squares namely ERR1, ERR2, ERROR and ERR1, ERROR were used respectively. Each of this error mean squares were used for calculating the F values for effects of variables above it.

Let us examine the effect of independent variables upon the indices of threshability. The "F" values can be regarded as basic criterion of comparison. In Table 2-A it can be noted that major variation is due to position, variety and clearance effects, while clearance by position and variety by position effects also produced considerable variation. Replication effect was insignificant even at 0.1 alpha level, suggesting that two replications were sufficient for concluding the results. Speed effects were also insignificant. A probable reason for this is that the chosen speeds were close together. In Table 2-B,C a similar trend in the results can be seen except that speed by position interaction was also significant. Thus the selected speeds had more effect on the distribution pattern of threshed than unthreshed material. Speed effect was also insignificant for the total unthreshed material.

While inspecting the results from torque-time curve data it can be seen that replication effect became significant at 0.1 alpha level in the analysis of area under the torque-time curve and was almost significant for maximum torque analysis at same alpha level. Thus a better control over the observations is needed. Other factors showed the similar pattern as the major variation was once again due to variety effect and its interactions with speed and clearance.

The major reason for performing the analysis of variance was not only to see the effects of factors under study but also to investigate whether any of the defined indices can detect the differences between varieties with respect to threshability. There is no doubt that major variation in each index is due to variety effect, telling us that there are differences between varieties with respect to threshing. Another reason for performing analysis of variance was to determine which of the indices is best. In order to find where significant differences between means exist and where the differences between indices were greatest, a least significant difference test (LSD 0.05 alpha level), on each index of threshability was run. Summarized results from these tests are shown in Appendix C.

TABLE 2. The analysis of variance for the data that were taken for distribution of threshed and unthreshed material along the concave.

A. Analysis of variance for unthreshed kernels - Count Basis

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	442.327	1.590
Speed	(S)	1	1374.190	4.940*
Clearance	(C)	2	9221.344	33.151**
S x C		2	367.001	1.319
ERR1		5	278.158	
Variety	(V)	12	6507.820	54.031**
S x V		12	164.517	1.366
C x V		24	218.633	1.815**
S x C x V		24	112.090	0.931
ERR2		72	120.446	
Position	(P)	6	14831.770	149.352**
S x P		6	54.076	0.544
C x P		12	558.726	5.626**
V x P		72	376.369	3.789**
S x C x P		12	150.492	1.515
S x V x P		72	81.978	0.825
C x V x P		144	88.546	0.891
S x C x V x P		144	64.093	0.645
ERROR		468	99.307	

Table 2. (Continued)

B. Analysis of variance for threshed kernels - Count Basis

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	92.055	0.033
Speed	(S)	1	6621.586	2.345
Clearance	(C)	2	17938.082	6.352*
S x C		2	2773.223	0.982
ERR1		5	2824.172	
Variety	(V)		57751.008	24.781**
S x V		12	1665.602	0.715
C x V		24	2587.164	1.110
S x C x V		24	1479.2197	0.635
ERR2		72	2330.476	
Position	(P)	6	2423684.000	3064.793**
S x P		6	3312.445	4.189**
C x P		12	5645.266	7.139**
V x P		72	4839.523	6.119**
S x C x P		12	596.891	0.755
S x V x P		72	461.687	0.584
C x V x P		144	584.493	0.739
S x C x V x P		144	491.270	0.621
ERROR		468	790.815	

Table 2. (Continued)

C. Analysis of variance for threshed kernels - Percentage Basis				
Source of Variation		DF	Mean Squares	F
Replication	(R)	1	1.016	0.864
Speed	(S)	1	3.341	2.841
Clearance	(C)	2	21.675	18.431**
S x C		2	3.505	2.980
ERR1		5	1.176	
Variety	(V)	12	18.789	35.925**
S x V		12	0.917	1.753*
C x V		24	1.149	2.197**
S x C x V		24	1.004	1.920**
ERR2		72	0.523	
Position	(P)	6	7257.019	3204.134**
S x P		6	8.623	3.807**
C x P		12	15.769	6.962**
V x P		72	17.478	7.717**
S x C x P		12	1.863	0.822
S x V x P		72	1.241	0.548
C x V x P		144	1.519	0.671
S x C x V x P		144	1.617	0.714
ERROR		468	2.265	

Table 2. (Continued)

D. Analysis of variance for total unthreshed kernels - Percentage Basis

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	4.061	0.653
Speed	(S)	1	33.148	5.333
Clearance	(C)	2	200.547	32.264**
S x C		2	7.346	0.209
ERR1		5	6.216	
Variety	(V)	12	101.741	44.014**
S x V		12	2.295	0.993
C x V		24	3.611	1.562*
S x C x V		24	1.943	0.840
ERROR		72	2.312	

*Significant at 0.10 alpha level.

**Significant at 0.05 alpha level.

TABLE 3. The analysis of variance for the data that were taken from torque-time curves.

A. Analysis of variance for maximum torque data

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	79.551	3.414
Speed	(S)	1	55.681	2.390
Clearance	(C)	2	149.602	6.420**
S x C		2	29.503	1.266
ERR1		5	23.301	
Variety	(V)	12	108.512	18.810**
S x V		12	12.752	2.210**
C x V		24	12.449	2.158**
S x C x V		24	4.765	0.826
ERROR		72	5.769	

B. Analysis of variance for area under torque-time curve

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	0.401	4.221*
Speed	(S)	1	0.333	3.505
Clearance	(C)	2	0.855	9.000**
S x C		2	0.416	4.379*
ERR1		5	0.095	
Variety	(V)	12	0.0444	15.116**
S x V		12	0.093	3.161
C x V		24	0.067	2.293**
S x C x V		24	0.086	2.910**
ERROR		72	0.029	

Table 3. (Continued)

C. Analysis of variance for span of torque-time curve

Source of Variation		DF	Mean Squares	F
Replication	(R)	1	4.536	1.353
Speed	(S)	1	4.673	1.394
Clearance	(C)	2	0.597	0.178
S x C		2	5.518	1.646
ERR1		5	3.353	
Variety	(V)	12	2.561	3.009**
S x V		12	1.203	1.413
C x V		24	1.264	1.485
S x C x V		24	1.219	1.432
ERROR		72	0.851	

*Significant at 0.10 alpha level.

**Significant at 0.05 alpha level.

Inspecting the LSD results in Appendix C, there is no doubt that first concave position plays an important part, as maximum number of classes were formed in this position both for threshed material (percentage basis) and unthreshed kernels (count and percentage basis). For threshed material (count basis) the second position differentiated most between varieties. Second clearance (mean clearance 5/16 in.) can be regarded as best clearance, as this clearance with the proper combination with speed created maximum differences, depending upon the index.

In Appendix C it can further be noted that data obtained from the torque-time curve formed less number of classes by LSD run for alpha = 0.05 level as against threshed and unthreshed material (count and percentage basis). But this difference in classes was not appreciable. One of the reasons for this is that torque-time curves were not very well behaved curves, as the torsional vibration of the main cylinder shaft caused a low signal to noise ratio. A better control over this problem can offer better opportunities for differentiation.

An effort was made to deduce some relation(s) between the indices so that the present results can be applied to the field conditions. It was possible to correlate the percentage threshed kernels obtained in the first position to the unthreshed kernels count basis, coming out at the back of the concave (7 th position). The coefficients thus obtained are presented in Table 4. Although conclusions about combine performance cannot be made until the present results are correlated with the combine data obtained under field conditions, similar results as obtained from the threshing unit can be expected for combine operating under normal harvesting conditions. Thus it would be possible to predict the unthreshed material coming at the back of the concave and separation requirement needed from straw walkers.

The unthreshed material though tells us about the threshing performance but a complete statement above the performance of the combine would not be possible without knowing the performance of the cleaning unit. Unthreshed material alone affects the performance in two ways. Either the cylinder loss will go up or the increased tailings will be recirculated which will cause an appreciable increase in grain to straw ratio. This can in turn cause an increase in walker free seed losses. Thus by sampling material at the first position along the concave and the recirculating tailings a better statement about combine performance is possible.

It is logical to expect that varieties which are easier to thresh will result in higher threshed material in the first position while lower values can be expected for the end position(s) and vice versa. A ratio of threshed kernels in first position with one of the end position will result in a number. The magnitude of this number will depend upon ease of threshing. The unthreshed material coming out at the back of the concave also depends upon the same. A ratio of threshed material at two different positions when correlated with unthreshed material might result in better correlation coefficients. Feed rate which is an important variable, can change the distribution pattern along the concave. A ratio will also reduce the effect of feed rate. Thus five different ratios P1/P3, P1/P4, P1/P5, P1/P6 and P1/P7 were tried. The correlation coefficients from these tests are given in Table 4. It can be seen that except only at three positions, most other resulted in lower correlation coefficients. Thus correlation tried in first place can be regarded a criterion for predicting combine performance.

TABLE 4. Correlation coefficients of unthreshed kernels (7 th position) with different variables.

Variable	Treatment Combination					
	S1 C1	S1 C2	S1 C3	S2 C1	S2 C2	S2 C3
P1	-0.58*	-0.78**	-0.49	-0.73**	-0.81**	-0.33
P1/P3	-0.59*	-0.48	-0.40	-0.58*	-0.49*	-0.49
P1/P4	-0.40	-0.73**	-0.32	-0.68*	-0.61*	-0.02
P1/P5	-0.71**	-0.58*	-0.17	-0.45	-0.61*	-0.20
P1/P6	-0.54	-0.45	-0.40	-0.67*	-0.80**	-0.33
P1/P7	-0.40	-0.54	-0.34	-0.50	-0.75**	-0.23

Explanation of terms and headings used in the table

P_i Threshed material (percentage basis) in i th position along concave

S1 The Speed; 1360 rpm.

S2 The Speed; 1480 rpm.

C1 The clearance; mean clearance, 3/16 in.

C2 The clearance; mean clearance, 5/16 in.

C3 The clearance; mean clearance, 7/16 in.

* Significant at 0.05 alpha level.

** Significant at 0.01 alpha level.

None of the indices obtained from the torque-time curve data correlated with any variables. A prime reason for this can be that these indices measure more than threshability and probably includes some of the physio-mechanical properties of the straw. These indices will be of more meaning if correlated with some of the physical quantities.

SUMMARY AND CONCLUSIONS

It is required now as much as in the past to avoid tedious and time consuming methods for assessing combine performance. Since threshing is the key operation during combining, a threshing unit was designed. Threshability of wheat was used as a means of predicting combine performance. Several indices of threshability were defined. The concave in this study was divided into six different compartments. The distribution pattern of threshed and unthreshed material was considered as a measure of threshability. Characteristics of the torque-time curves obtained at the main cylinder shaft were also considered as threshability parameters. Area, span and height of the torque-time curve were considered as three indices of interest. Thirteen different wheat varieties were used. The effect of two machine parameters, speed and clearance was observed. Two speed levels 1360 and 1480 rpm. and three clearances; mean clearance of 3/16, 5/16, and 7/16 in. were used. Correlation between different indices was tried. A relation between distribution pattern of unthreshed and threshed material along the concave was found by simple linear correlation.

The conclusions drawn from experimental results were as follows;

1. Clearance effected the distribution pattern of threshed grain along the concave length more than the speeds in use.
2. The speed effect was more pronounced on the distribution pattern of threshed than unthreshed material. The speed in use also did not produce a significant difference in total unthreshed material.
3. Of different defined indices, each index was capable of differentiating between varieties, since variety effect in each parameter was highly significant.

4. First position along the concave is the key position that correlated best with unthreshed grain. Most of the classes by LSD run were formed in this position.

5. There exists a relationship between the percentage threshed material obtained in first position and unthreshed material passed at the back of the concave. This relation has potential for partial prediction of combine performance if same relation is found for combine operating under field conditions.

6. To reduce the effect of feed rate and to improve the relationship mentioned above, simple linear correlations between the unthreshed kernels passed at the back of the concave and five different ratios were tried. These ratios were obtained by dividing percentage threshed grain at two different positions along the length of the concave. No improved relations were found.

7. Threshability parameters obtained from torque-time curves differentiated between varieties but no conclusive results were found.

SUGGESTIONS FOR FUTURE WORK

1. Vibration problem in threshing cylinder must be reduced. A better signal to noise ratio would result in a well behaved torque-time curve.
2. Tests should be performed under field conditions to examine whether a similar or better relation exist.
3. Test other grain crops which are generally harvested by combine.
4. In the field, threshing is a continuous operation. The same experiment should be conducted with continuous feed rate to examine whether the methods established in batch feeding can be used for continuous feed rate, and if same or better relations exist.
5. Some physical crop parameters which are expected to affect threshability should be included.
6. If speed of the cylinder is included as a machine parameter in future, a wider speed variation should be used.
7. Some method(s) of improving the relation between the indices should be examined.
8. Mathematical model which predicts combine performance would be helpful. This model should contain sufficient variables so that it can be used under wide variety of crop conditions.

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APPENDICES

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APPENDIX A

Number of Unthreshed and Threshed Kernels Along the Length of the Concave

C O U N T   D A T A

SPEED = 1360   REPLICATION 1   CLEARANCE = 3/16

NO.	VARIETY	POSITION-1 **	POSITION-1 ***	POSITION-2 **	POSITION-2 ***	POSITION-3 **	POSITION-3 ***	POSITION-4 **	POSITION-4 ***	POSITION-5 **	POSITION-5 ***	POSITION-6 **	POSITION-6 ***	POSITION-7 **	POSITION-7 ***
1	PARKER	13	420	5	269	2	174	3	182	4	91	3	192	5	264	6	33
2	PRONTO	41	469	18	317	7	194	6	170	6	122	5	213	16	346	7	60
3	CENTURK	17	531	13	360	6	214	4	221	2	143	6	195	51	360	3	39
4	TR--64	8	498	4	275	0	153	2	160	0	84	1	172	15	263	1	26
5	SATANTA	21	492	11	339	11	217	21	189	6	107	13	224	24	319	7	44
6	SCOUT	17	369	14	219	7	164	5	162	3	87	3	183	10	269	6	29
7	EAGLE	15	385	10	257	5	162	3	144	4	95	10	206	32	278	32	48
8	TURKEY	5	491	0	254	3	147	1	181	1	86	5	210	5	304	50	99
9	CHANUTE	36	526	27	323	8	205	5	199	9	149	19	258	21	329	5	56
10	GAGE	17	475	11	282	3	194	3	152	0	111	3	199	11	313	17	99
11	SHAWNEE	8	452	13	284	8	172	2	170	3	97	8	182	7	273	4	23
12	REDCHIEF	51	373	21	272	11	176	18	152	8	78	13	194	23	300	6	45
13	DANNE	16	460	12	319	7	165	11	161	3	87	6	216	14	290	1	37

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1360   REPLICATION 1   CLEARANCE = 5/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	13	533	3	261	11	152	1	141	2	74	3	172	9	219	37	43
2	PRONTO	38	467	25	330	25	220	13	193	8	89	20	207	31	356	2	27
3	CENTURK	34	640	47	385	13	195	14	178	4	104	10	258	25	253	17	59
4	TR---64	21	506	5	234	2	190	2	120	1	67	1	149	2	263	4	51
5	SATANTA	31	472	25	305	12	183	13	186	17	86	26	178	68	253	7	44
6	SCOUT	30	535	12	252	3	118	6	117	10	57	11	149	36	253	64	34
7	EAGLE	14	454	22	275	0	155	16	138	7	74	12	210	15	280	5	35
8	TURKEY	9	446	4	272	5	130	7	143	1	56	1	143	48	234	70	99
9	CHANUTE	59	510	37	347	23	217	17	214	13	140	28	266	60	321	4	37
10	GAGE	21	457	19	306	12	210	12	139	4	93	2	172	15	251	43	68
11	SHAWNEE	18	458	5	246	25	173	13	154	0	73	3	151	9	222	28	26
12	REDCHIEF	58	317	39	210	23	131	19	146	7	79	22	169	37	279	99	99
13	DANNE	21	452	11	328	4	174	5	177	6	98	12	232	22	326	5	48
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

COUNT DATA

SPEED = 1360 REPLICATION 1 CLEARANCE = 7/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	22	426	4	290	6	170	2	137	4	84	7	159	16	205	1	25
2	PRONTO	46	314	49	283	26	214	29	176	18	116	26	185	99	244	8	20
3	CENTURK	46	456	39	430	39	261	22	204	10	122	14	262	99	346	10	53
4	TR---64	14	534	6	291	0	142	0	146	0	89	0	178	14	246	0	25
5	SATANTA	36	520	22	305	20	184	21	173	5	89	8	181	69	292	2	21
6	SCOUT	17	363	22	303	17	176	10	157	14	95	9	147	70	208	7	25
7	EAGLE	27	400	29	254	9	168	26	144	5	93	5	144	21	223	6	48
8	TURKEY	31	469	5	286	23	148	8	147	8	77	1	160	71	215	12	91
9	CHANUTE	49	525	38	309	15	204	13	156	5	93	41	196	60	318	5	51
10	GAGE	14	439	9	301	19	186	16	153	6	109	6	166	52	232	8	43
11	SHAWNEE	24	430	7	299	2	161	11	163	3	92	5	177	31	220	3	15
12	REDCHIEF	45	236	63	216	15	150	65	147	23	81	30	172	68	290	52	34
13	DANNER	11	111	11	111	11	111	11	111	11	111	11	111	11	111	11	11
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1480   REPLICATION 1   CLEARANCE = 3/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	4	473	8	264	2	170	1	144	1	85	6	169	3	240	14	42
2	PRONTO	22	522	13	335	4	200	4	196	5	133	14	204	24	314	33	40
3	CENTURK	27	656	10	377	2	220	5	205	5	130	7	249	15	335	4	28
4	TS---64	3	506	3	266	1	162	1	146	1	93	3	174	4	278	4	40
5	SATANTA	35	491	19	270	12	160	5	162	5	97	14	196	22	284	5	54
6	SCOUT	20	470	8	265	5	164	2	129	5	67	6	185	16	300	5	34
7	EAGLE	11	407	7	280	5	161	3	142	1	67	5	161	8	239	2	40
8	TURKEY	8	521	2	259	2	160	1	129	0	66	0	170	5	262	3	99
9	CHANUTE	54	585	20	323	16	208	11	198	3	72	13	263	30	336	11	63
10	GAGE	15	551	7	287	6	184	9	150	3	67	7	202	19	331	20	56
11	SHAWNEE	11	445	5	248	7	171	2	159	2	98	4	187	32	289	2	59
12	REDCHIEF	33	396	13	249	12	170	2	177	7	89	12	184	17	304	50	63
13	DANNEE	15	481	7	305	4	210	0	203	3	134	7	224	17	332	34	34
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1480   REPLICATION 1   CLEARANCE = 5/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	8	479	6	288	2	177	3	143	1	82	6	147	2	223	2	71
2	PRONTO	40	523	32	338	15	162	4	150	5	83	21	185	29	312	3	17
3	CENTURK	27	673	46	381	3	208	10	209	4	138	7	241	11	295	8	68
4	TR---64	4	502	4	290	2	157	0	148	1	93	1	165	2	254	4	34
5	SATANTA	18	424	12	270	7	181	0	130	1	92	6	175	14	257	18	24
6	SCOUT	34	451	25	315	12	182	18	159	13	90	11	190	15	260	9	56
7	EAGLE	30	442	26	246	9	245	8	165	3	97	4	178	4	254	19	56
8	TURKEY	3	442	7	306	1	172	5	161	1	83	1	164	7	291	8	99
9	CHANUTE	37	553	30	372	13	220	13	165	10	101	9	239	53	352	34	53
10	GAGE	20	530	3	295	3	170	7	141	0	90	6	158	12	258	37	41
11	SHAWNEE	18	585	5	274	5	161	0	129	1	75	1	195	4	311	4	38
12	REDCHIEF	42	344	24	280	7	180	9	195	13	92	19	194	31	340	6	44
13	DANNE?	25	503	16	306	7	189	7	155	10	78	7	191	16	298	25	95
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1480   REPLICATION 1   CLEARANCE = 7/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	12	497	11	271	13	137	6	146	3	84	3	164	20	214	8	67
2	PRONTO	30	390	22	305	23	199	11	175	15	125	14	208	61	290	6	32
3	CENTURK	34	511	34	422	20	264	16	205	10	107	8	231	98	314	30	54
4	TR---64	5	431	4	310	6	182	8	138	0	81	5	158	17	204	0	20
5	SATANTA	48	465	41	362	29	213	7	182	7	119	22	206	76	265	5	30
6	SCOUT	34	375	40	255	6	159	17	131	3	90	15	183	99	245	4	29
7	EAGLE	22	420	20	232	13	143	14	117	15	76	3	188	48	252	40	42
8	TURKEY	8	484	13	316	4	170	4	141	2	78	7	190	37	265	4	51
9	CHANUTE	57	489	31	385	18	231	19	205	11	97	42	230	57	309	5	37
10	GAGE	29	529	10	300	12	159	18	141	6	65	5	184	56	276	28	60
11	SHAWNEE	17	448	9	296	4	189	5	148	5	102	3	185	26	200	6	38
12	REDCHIEF	34	338	34	223	17	115	19	121	31	81	41	184	60	314	64	62
13	DANNER	42	484	29	347	10	167	17	190	4	85	18	207	30	295	0	15
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1360   REPLICATION 2   CLEARANCE = 3/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	11	525	3	237	3	141	2	126	1	66	3	145	6	220	30	42
2	PRONTO	39	428	20	331	13	212	19	158	13	103	37	246	49	327	0	20
3	CENTURK	19	586	15	381	3	266	10	194	5	122	9	297	26	379	25	70
4	TB---64	3	501	2	267	0	130	0	133	1	60	2	160	8	235	5	27
5	SATANTA	38	565	27	284	12	168	9	155	12	96	11	196	46	310	3	22
6	SCOUT	21	357	25	241	9	127	10	137	1	87	8	175	36	276	2	25
7	EAGLE	9	366	11	233	5	161	5	139	5	80	12	172	17	258	21	41
8	TURKEY	9	444	9	248	3	164	2	147	1	80	1	171	8	288	30	97
9	CHANUTE	42	567	30	348	13	188	27	186	10	117	32	227	59	323	10	48
10	GAGE	29	520	6	327	10	171	6	192	2	102	9	209	12	329	13	86
11	SHAWNEE	21	474	5	237	2	142	2	140	2	67	3	165	2	256	23	18
12	REDCHIEF	53	421	15	279	15	160	9	154	5	75	11	205	19	311	40	35
13	DANNE	11	509	6	325	4	194	9	161	7	97	5	208	16	351	10	54
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

COUNT DATA

SPEED = 1360 REPLICATION 2 CLEARANCE = 5/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	18	435	3	279	0	161	3	133	2	98	5	159	4	242	2	99
2	PRONTO	44	443	27	297	17	192	24	163	14	98	18	225	99	339	25	40
3	CENTURK	33	573	27	363	18	226	9	207	8	122	9	249	52	358	7	64
4	TR---64	5	427	2	285	0	150	1	153	1	91	2	183	10	277	2	37
5	SATANTA	39	494	20	328	22	167	16	165	10	99	23	182	26	232	32	24
6	SCOUT	15	428	23	301	3	197	11	162	7	114	13	203	40	261	7	27
7	EAGLE	22	462	15	280	5	158	12	141	4	74	10	197	17	265	1	30
8	TURKEY	13	470	6	270	5	172	2	120	2	80	7	142	47	230	34	65
9	CHANUTE	63	562	44	369	16	229	25	191	10	142	28	242	44	342	3	50
10	GAGE	16	476	11	291	3	167	2	127	1	65	7	164	10	256	3	44
11	SHAWNEE	13	477	7	269	22	172	4	126	2	66	4	174	20	254	8	44
12	REDCHIEF	87	345	41	226	14	150	16	127	13	74	35	166	79	278	99	57
13	DANNER	37	567	10	330	4	181	15	172	3	91	6	225	18	324	31	28
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1360   REPLICATION 2   CLEARANCE = 7/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	18	483	12	278	6	151	2	131	2	77	7	154	54	223	0	40
2	PRONTO	54	466	40	302	16	189	12	163	15	87	41	208	60	288	27	60
3	CENTURK	39	548	46	369	69	222	44	161	8	120	17	234	35	285	41	51
4	TR---64	4	484	6	251	2	150	3	127	2	68	8	148	7	229	2	26
5	SATANTA	43	430	35	328	19	193	22	189	8	86	22	195	18	278	0	25
6	SCOUT	35	453	20	266	15	160	5	128	3	76	10	133	25	218	19	22
7	EAGLE	33	381	29	273	8	154	14	162	4	75	13	160	22	259	4	27
8	TURKEY	12	397	13	281	19	150	1	144	9	75	11	157	60	232	26	99
9	CHANUTE	52	438	45	303	33	194	18	181	8	118	45	208	91	314	36	78
10	GAGE	23	440	12	283	2	173	9	178	8	106	19	159	18	248	9	37
11	SHAWNEE	12	512	14	323	24	160	2	127	1	94	6	154	42	246	8	23
12	REDCHIEF	99	310	85	252	26	172	21	172	15	103	36	225	35	316	40	32
13	DANNEE	38	614	16	345	10	196	6	154	3	66	8	177	26	341	16	73
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1480   REPLICATION 2   CLEARANCE = 3/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	10	514	5	212	2	151	3	112	3	67	4	122	4	221	13	95
2	PRONTO	32	411	19	320	24	179	10	173	6	121	12	203	36	322	4	34
3	CENTURK	34	620	15	384	6	225	6	215	5	124	10	243	28	347	13	78
4	TR---64	4	459	3	214	1	144	0	124	1	65	0	158	0	286	57	93
5	SATANTA	38	465	18	308	15	159	10	165	3	107	14	219	41	269	3	58
6	SCOUT	21	403	8	246	3	158	6	150	3	71	3	186	21	293	3	48
7	EAGLE	17	483	14	205	3	144	8	120	1	77	3	167	70	264	9	50
8	TURKEY	12	451	5	242	1	135	0	149	3	78	3	174	8	256	45	99
9	CHANUTE	46	529	35	343	14	182	8	192	7	110	22	223	99	360	5	76
10	GAGE	19	556	12	277	3	191	4	164	1	93	1	176	4	267	4	38
11	SHAWNEE	11	472	2	249	4	147	1	130	0	73	1	163	25	210	14	28
12	REDCHIEF	51	407	32	231	9	175	8	147	8	71	16	187	53	345	11	69
13	DANNE	25	550	9	302	7	160	5	185	3	98	8	226	21	349	2	58
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

COUNT DATA

SPEED = 1480 REPLICATION 2 CLEARANCE = 5/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	10	548	6	313	4	165	4	122	3	69	2	130	4	176	2	43
2	PRONTO	47	423	33	351	10	233	15	219	7	127	15	254	55	356	6	50
3	CENTURK	32	582	19	382	13	224	11	195	8	140	15	217	20	326	4	41
4	TR---64	6	456	4	279	2	168	0	135	1	72	5	157	9	250	0	20
5	SATANTA	36	505	28	369	15	197	12	191	14	115	21	234	28	315	8	61
6	SCOUT	24	457	15	306	5	137	7	150	2	100	5	154	52	243	6	23
7	EAGLE	25	447	10	291	7	167	5	151	3	103	7	167	24	251	5	36
8	TURKEY	9	495	5	283	2	146	5	135	3	74	7	173	7	238	12	99
9	CHANUTE	38	519	31	396	23	228	12	189	16	109	36	245	25	337	29	97
10	GAGE	15	472	11	345	1	188	3	164	3	82	7	167	10	265	33	33
11	SHAWNEE	20	519	5	290	2	159	2	117	2	75	4	133	12	206	0	30
12	REDCHIEF	62	382	21	233	25	162	7	137	5	91	30	169	37	290	60	30
13	DANNE	36	695	10	346	5	192	4	165	3	96	11	247	20	298	6	37
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

C O U N T   D A T A

SPEED = 1480   REPLICATION 2   CLEARANCE = 7/16

NO.	VARIETY	**	***	**	***	**	***	**	***	**	***	**	***	**	***	**	***
1	PARKER	20	485	26	306	4	157	7	148	3	75	2	142	7	199	24	51
2	PRONTO	43	475	34	297	15	195	7	166	6	106	15	202	27	303	19	46
3	CENTURK	45	517	22	282	16	172	4	127	5	68	3	170	52	244	5	31
4	TR---64	4	491	2	264	5	173	1	129	1	83	2	173	33	223	2	32
5	SATANTA	54	549	36	314	26	205	29	147	2	88	7	205	22	289	9	37
6	SCOUT	25	478	6	311	4	184	2	155	9	84	14	147	7	259	5	35
7	EAGLE	32	483	27	293	12	175	5	152	8	96	8	175	38	266	3	36
8	TURKEY	10	477	16	279	2	175	8	153	8	79	10	140	20	256	19	87
9	CHANUTE	99	560	45	332	31	189	17	174	7	102	39	212	29	308	49	99
10	GAGE	13	425	17	292	6	178	4	194	5	106	15	210	39	309	29	64
11	SHAWNEE	13	462	8	274	5	136	4	131	5	82	5	138	91	221	1	36
12	REDCHIEF	93	324	98	219	18	135	13	130	26	67	23	174	34	292	88	50
13	DANNE	14	528	12	339	7	182	10	196	6	78	4	166	33	296	7	33
		POSITION-1		POSITION-2		POSITION-3		POSITION-4		POSITION-5		POSITION-6		POSITION-7			

** NUMBER OF UNTHRESHED KERNELS

*** NUMBER OF THRESHED KERNELS

APPENDIX A (Continued)

T O R Q U E   T I M E   C U R V E   D A T A

SPEED = 1360   CLEARANCE = 3/16

		REPLICATION 1			REPLICATION 2		
NO.	VARIETY	MAX. TORQUE	AREA	SPAN	MAX. TORQUE	AREA	SPAN
1	PARKER	17.5	1.30	5.4	13.8	0.80	2.6
2	PRONTO	19.0	1.35	4.4	24.2	1.51	4.9
3	CENTURK	19.0	1.52	6.0	14.0	1.07	3.8
4	TR---64	21.0	1.05	2.5	16.1	0.93	3.6
5	SATANTA	23.5	1.74	5.1	20.0	0.90	2.8
6	SCOUT	15.2	0.91	3.5	11.9	0.84	3.6
7	EAGLE	20.0	0.84	2.3	9.0	0.71	3.7
8	TURKEY	14.0	1.00	4.0	8.5	0.55	2.9
9	CHANUTE	28.7	2.27	5.1	22.5	1.57	4.7
10	GAGE	13.8	1.00	5.0	12.3	0.80	3.0
11	SHAWNEE	13.0	0.75	3.2	12.5	0.84	3.9
12	REDCHIEF	10.0	0.59	3.3	10.0	0.59	4.5
13	DANNFE	15.0	1.29	4.0	15.0	1.29	4.1

*** UNITS

MAX. TORQUE	LINES DEFLECTIONS.
AREA	SQUARE INCHES.
SPAN	SECONDS.

APPENDIX A (Continued)

TORQUE TIME CURVE DATA

SPEED = 1360 CLEARANCE = 5/16

		REPLICATION 1			REPLICATION 2		
NO.	VARIETY	MAX. TORQUE	AREA	SPAN	MAX. TORQUE	AREA	SPAN
1	PARKER	10.5	0.85	5.2	22.2	1.47	6.3
2	PRONTO	19.0	1.66	5.0	22.0	1.50	3.7
3	CENTURK	15.0	0.95	4.0	9.5	0.88	7.3
4	TR---64	17.8	1.27	3.3	17.8	1.27	6.2
5	SATANTA	12.8	0.76	6.5	12.8	0.76	5.3
6	SCOUT	12.5	1.00	5.0	17.0	1.45	6.5
7	EAGLE	13.5	0.90	3.8	13.5	0.90	5.1
8	TURKEY	7.8	0.50	3.7	7.8	0.50	3.2
9	CHANUTE	19.5	0.88	4.8	21.0	1.29	4.7
10	GAGE	12.0	0.67	2.9	11.0	0.66	3.0
11	SHAWNEE	10.0	0.52	2.9	11.2	0.56	3.6
12	REDCHIEF	9.8	0.66	2.7	5.8	0.47	4.2
13	DANNE	15.5	1.03	5.8	13.0	1.26	5.2

*** UNITS

MAX. TORQUE	LINES DEFLECTIONS.
AREA	SQUARE INCHES.
SPAN	SECONDS.

APPENDIX A (Continued)

TORQUE TIME CURVE DATA

SPEED = 1360 CLEARANCE = 7/16

		REPLICATION 1			REPLICATION 2		
NO.	VARIETY	MAX. TORQUE	AREA	SPAN	MAX. TORQUE	AREA	SPAN
1	PARKER	10.1	0.50	4.5	10.1	0.50	6.0
2	PRONTO	8.1	0.41	3.1	8.1	0.41	3.8
3	CENTURK	13.8	0.70	4.1	12.7	0.70	3.9
4	TR---64	16.0	0.90	3.9	16.0	0.90	2.5
5	SATANTA	15.2	1.12	4.8	12.7	0.83	5.8
6	SCOUT	9.3	0.58	5.0	10.0	0.63	6.3
7	EAGLE	9.6	0.60	3.2	11.1	0.73	5.9
8	TURKEY	9.5	0.43	2.5	7.0	0.31	3.3
9	CHANUTE	13.1	1.03	6.0	15.8	1.20	9.5
10	GAGE	9.5	0.38	3.8	9.5	0.38	4.5
11	SHAWNEE	12.0	0.64	3.8	10.0	0.55	5.5
12	REDCHIEF	11.8	0.78	4.3	9.0	0.39	5.5
13	DANNEE	14.0	1.00	3.2	8.5	0.49	3.2

*** UNITS

MAX. TORQUE	LINES DEFLECTIONS.
AREA	SQUARE INCHES.
SPAN	SECONDS.

APPENDIX A (Continued)

TORQUE TIME CURVE DATA

SPEED = 1480 CLEARANCE = 3/16

		REPLICATION 1			REPLICATION 2		
NO.	VARIETY	MAX. TORQUE	AREA	SPAN	MAX. TORQUE	AREA	SPAN
1	PARKER	13.0	0.61	2.8	13.0	0.61	5.4
2	PRONTO	19.2	1.17	4.0	19.2	1.17	5.5
3	CENTURK	9.7	0.68	4.5	9.7	0.68	4.4
4	TR---64	15.1	1.04	5.5	12.0	0.77	3.9
5	SATANTA	18.8	0.90	2.7	11.0	0.60	3.5
6	SCOUT	16.0	1.19	5.4	16.0	1.19	3.5
7	EAGLE	13.5	0.57	2.7	11.0	0.72	5.3
8	TURKEY	8.0	0.47	3.0	6.3	0.42	2.6
9	CHANUTE	21.0	0.96	3.0	17.0	0.89	5.8
10	GAGE	10.2	0.85	5.5	12.9	0.55	5.8
11	SHAWNEE	9.0	0.48	3.9	9.0	0.48	4.0
12	REDCHIEF	10.2	0.89	4.5	9.1	0.77	5.6
13	DANNER	18.1	1.00	3.9	20.0	1.06	5.5

*** UNITS

MAX. TORQUE	LINES DEFLECTIONS.
AREA	SQUARE INCHES.
SPAN	SECONDS.

APPENDIX A (Continued)

T O R Q U E   T I M E   C U R V E   D A T A

SPEED = 1480 | CLEARANCE = 5/16

		REPLICATION 1			REPLICATION 2		
NO.	VARIETY	MAX. TORQUE	AREA	SPAN	MAX. TORQUE	AREA	SPAN
1	PARKER	12.0	0.90	4.7	12.2	0.55	2.7
2	PRONTO	16.0	1.05	3.7	19.5	0.66	2.6
3	CENTURK	9.0	0.45	3.7	9.0	0.45	4.0
4	TR---64	15.8	1.19	5.0	16.9	0.91	3.3
5	SATANTA	11.8	0.89	4.0	15.0	1.10	5.5
6	SCOUT	12.9	1.05	4.7	16.0	1.24	4.4
7	EAGLE	13.0	0.81	5.1	13.0	0.81	3.8
8	TURKEY	7.5	0.53	2.6	7.5	0.53	3.7
9	CHANUTE	19.8	1.32	5.5	10.6	0.66	4.7
10	GAGE	11.5	1.27	4.7	10.0	0.79	3.4
11	SHAWNEE	10.0	0.90	4.2	12.5	0.75	3.6
12	REDCHIEF	7.5	0.58	4.2	7.5	0.58	3.0
13	DANNEE	18.2	1.41	4.4	17.0	0.95	3.0

*** UNITS

MAX. TORQUE	LINES DEFLECTIONS.
AREA	SQUARE INCHES.
SPAN	SECONDS.

APPENDIX A (Continued)

TORQUE TIME CURVE DATA

SPEED = 1480 CLEARANCE = 7/16

NO.	VARIETY	REPLICATION 1 MAX. TORQUE	AREA	SPAN	REPLICATION 2 MAX. TORQUE	AREA	SPAN
1	PARKER	13.8	0.82	3.8	9.1	0.71	4.5
2	PRONTO	15.4	1.22	4.5	13.5	0.63	3.1
3	CENTURK	15.1	1.10	3.9	8.0	0.50	4.1
4	TR---64	16.8	0.71	2.5	13.4	0.70	3.8
5	SATANTA	17.5	0.90	3.0	8.5	0.69	4.4
6	SCOUT	15.5	0.97	4.1	8.5	0.78	5.4
7	EAGLE	10.2	0.62	3.9	12.5	0.82	4.0
8	TURKEY	9.0	0.68	3.1	6.8	0.58	4.0
9	CHANUTE	18.0	0.97	3.0	8.0	0.50	3.1
10	GAGE	9.0	0.57	2.6	9.9	0.72	3.8
11	SHAWNEE	10.2	0.55	2.8	7.6	0.53	4.1
12	REDCHIEF	9.7	0.62	2.4	6.2	0.63	5.0
13	DANNEE	17.0	1.05	3.8	10.0	0.69	3.6

*** UNITS

MAX. TORQUE LINES DEFLECTIONS.
AREA SQUARE INCHES.
SPAN SECONDS.

APPENDIX C

Number of classes formed for defined indices by LSD at 0.05 alpha level.

A. $LSD_{0.05}$ for indices where either speed by clearance by variety by position or speed by clearance by variety means were arranged.

Index		Treatment Combination					
		S_1C_1	S_1C_2	S_1C_3	S_2C_1	S_2C_2	S_2C_3
Threshed kernels (percentage basis)	P_1	5	6	7	7	8	6
	P_2	1	2	4	2	3	2
	P_3	1	1	1	1	1	2
	P_4	1	1	1	1	1	1
	P_5	1	1	2	1	1	1
	P_6	1	2	1	1	1	1
	P_7	1	3	2	2	3	2
Threshed kernels (count basis)	P_1	6	4	6	6	6	6
	P_2	6	7	5	4	5	6
	P_3	3	4	3	2	3	4
	P_4	2	3	1	5	3	2
	P_5	2	2	1	1	3	1
	P_6	4	4	5	4	6	2
	P_7	6	4	3	4	6	3
Maximum torque (torque-time curve)		6	5	4	4	5	3
Area under the torque time curve		5	7	5	5	5	2

APPENDIX C. (Continued)

B. $LSD_{0.05}$ for the indices where either clearance by variety by position or clearance by variety means were arranged.

Index		Treatment Combination		
		C_1	C_2	C_3
Total unthreshed kernels (percentage basis)		6	5	4
Unthreshed kernels (count basis)	P_1	6	8	5
	P_2	5	7	6
	P_3	1	4	5
	P_4	1	2	3
	P_5	1	1	2
	P_6	3	3	4
	P_7	6	6	7

Explanation of terms and headings used in the table

- P_i i th position along the concave.
- S_1 The speed; 136 rpm.
- S_2 The speed; 1480 rpm.
- C_1 The clearance; mean clearance, 3/16 in.
- C_2 The clearance; mean clearance, 5/16 in.
- C_3 The clearance; mean clearance, 7/16 in.

A COMPARISON OF FIVE WHEAT THRESHABILITY PARAMETERS USING AN INSTRUMENTED LABORATORY CYLINDER

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Combine performance is of major concern to both the manufacturer and the farmer. The existing approach is direct. It is based on the actual assessment of the losses which occur at different places in a combine. Although these methods are reliable for predicting combine performance, considerable data is required. Excessive time, cost of maintaining trained staff, effort involved, and unpredictable weather conditions are a source of discouragement for carrying out these experiments. For this reason an experimental study was made to develop a new method as a possible alternative to the present day techniques. The degree of threshing occurring in a combine cylinder is of great importance. Machine losses which occur from rack and shoe may be predicted if degree of threshing operation is known. The study was thus based on the development of some quantitative measure of crop threshability parameters (threshing indices), comparison of these indices, and determination of the effect of selected machine variables on the defined indices.

To obtain new method of measuring threshability parameters, an instrumented threshing unit was designed. Threshing unit consisted of conventional 12 in. rasp bar cylinder (7-1/4 in. wide), with an open concave (130 degrees). The concave was partitioned along its length so that the front-to-back distribution pattern of material passing through the concave could be determined. Five threshability indices were defined. Two of these defines indices (percentage of threshed material in each divided portion of the concave, and total percentage of unthreshed material) were based on the distribution pattern of the material. The other three indices (maximum torque, area,

and the span of the torque-time curve) were obtained from the characteristics of the torque-time curves. These curves were obtained from a specially designed torque-transducer at the main cylinder shaft.

Thirteen different wheat varieties were used in this study. Two machine parameters, cylinder speed and cylinder to concave clearance were chosen to determine their effect on the defined threshability parameters. The conclusions drawn from experimental results were as follows:

1. The clearance effect was more pronounced on the defined indices than the speeds which were used.
2. Of different defined indices each index is capable of differentiating between varieties.
3. First position along the concave is a key position. Maximum differences between varieties, with respect to threshing, exist in this position.
4. It was possible to correlate the percentage of threshed material in the first divided position along the concave to total threshed material and also to the unthreshed material passed at the back of the concave. These relations can be used for partial prediction of combine performance.
5. Although no conclusive results could be drawn from the torque-time curve data, these indices cannot be regarded useless unless no relations are found between these indices and some physical crop properties.

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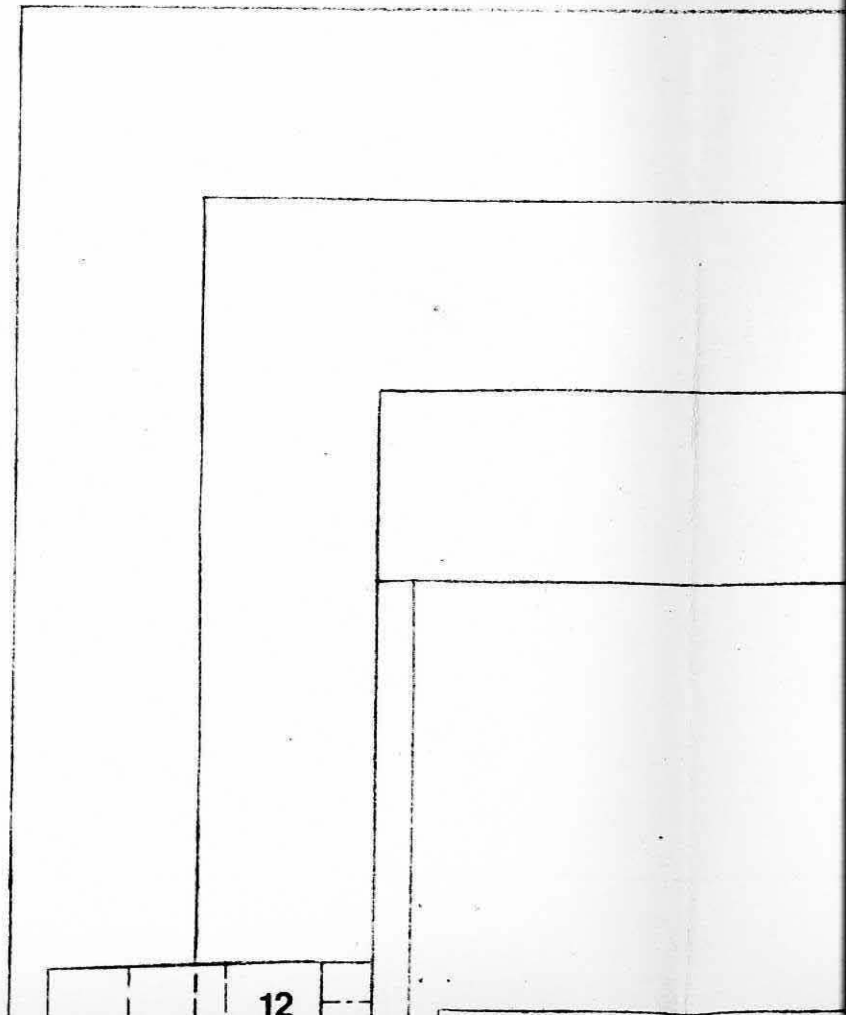
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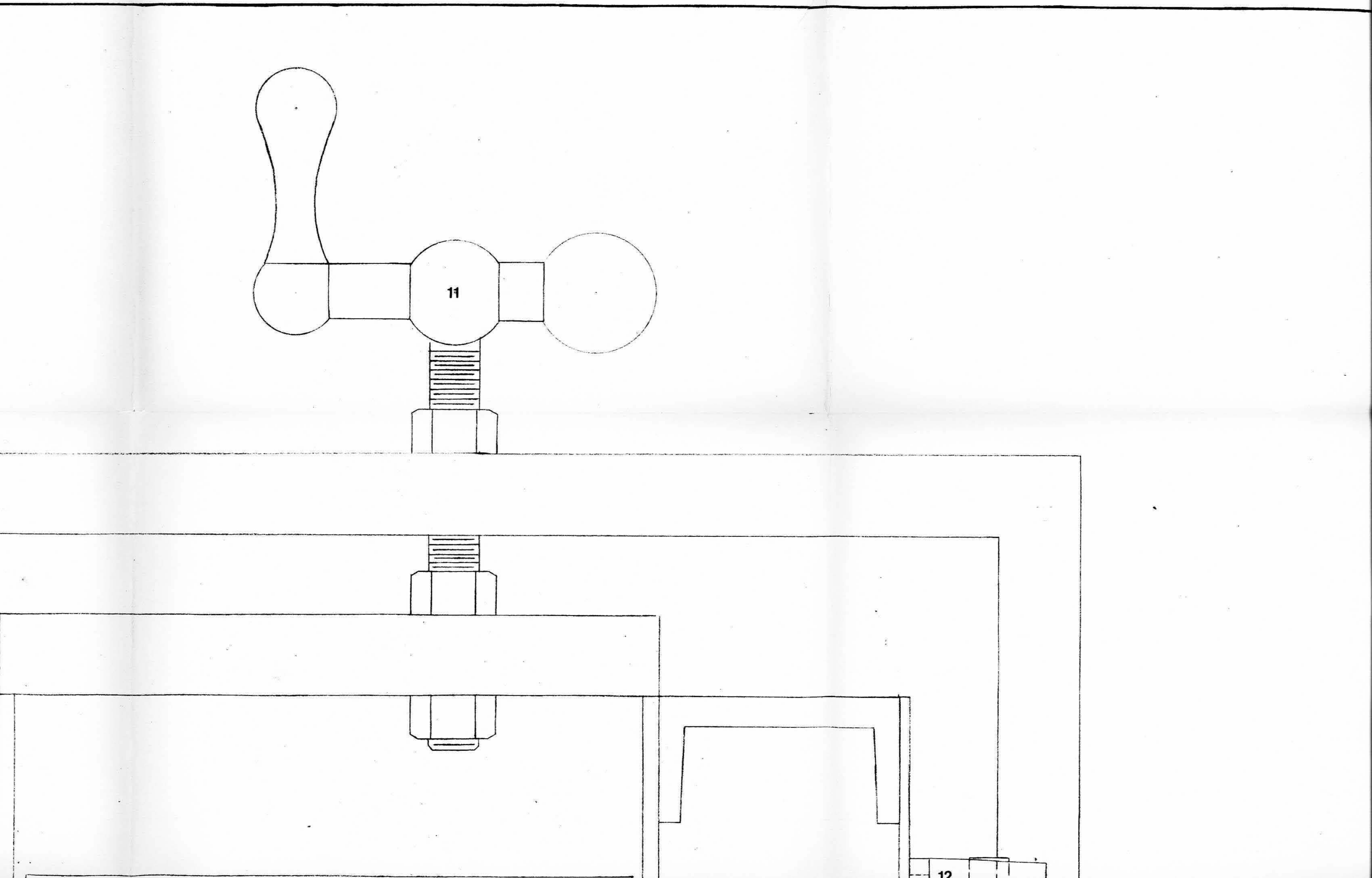
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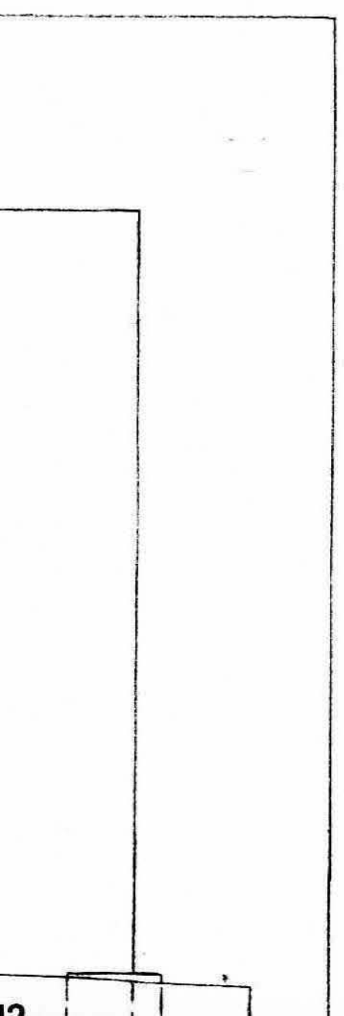
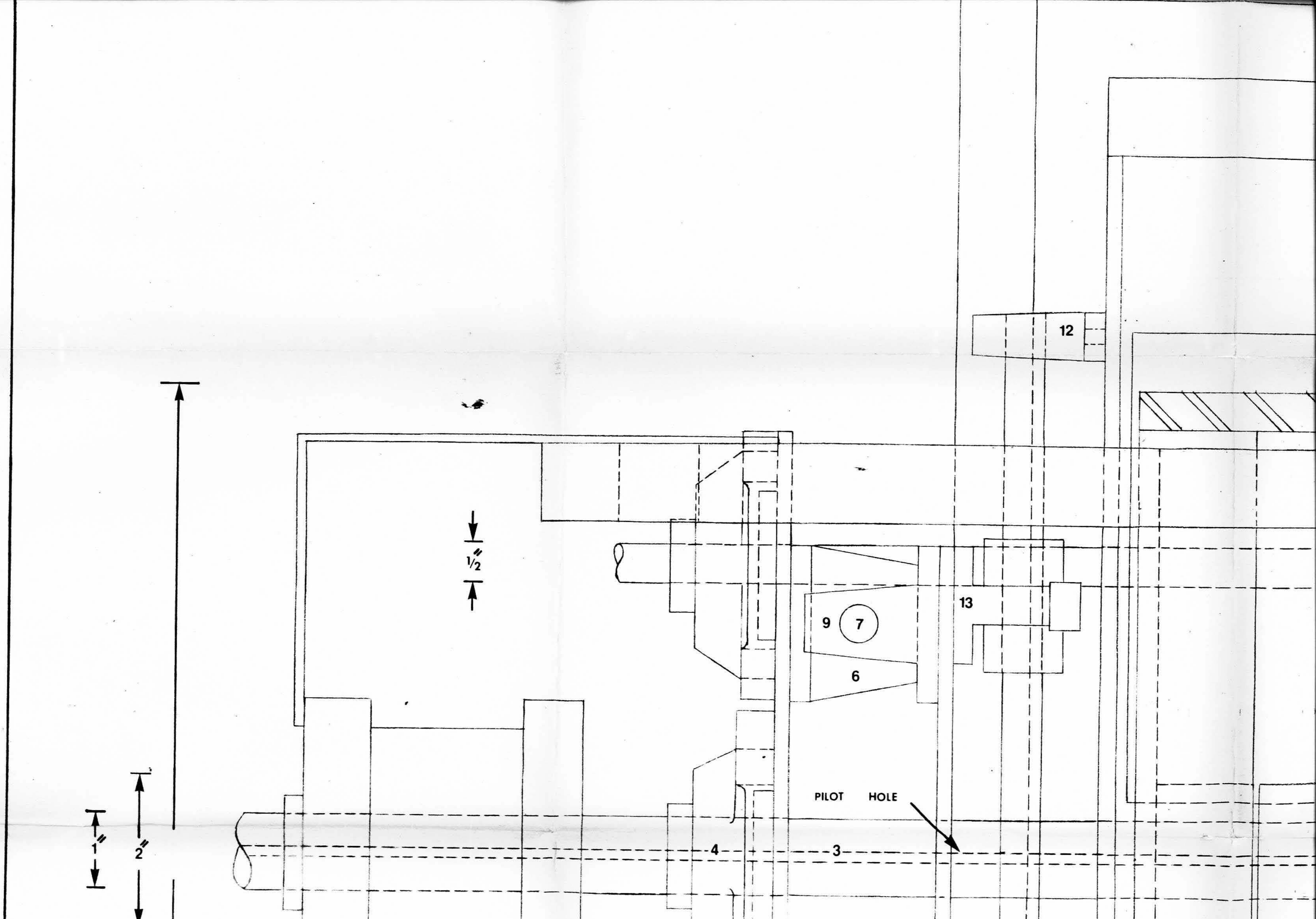
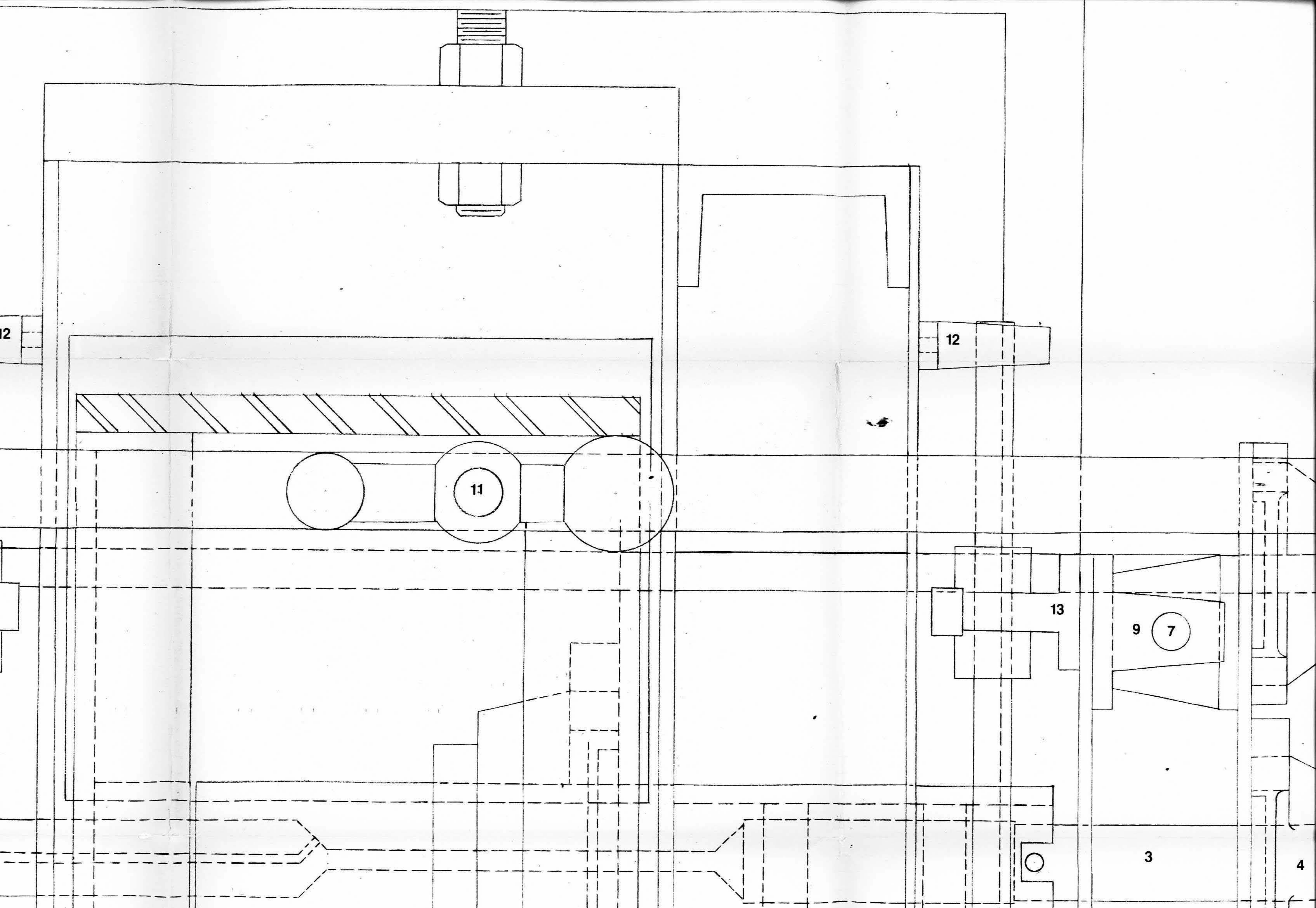




12
1/2"
13
9
7
6
PILOT HOLE
4
3
1"
2"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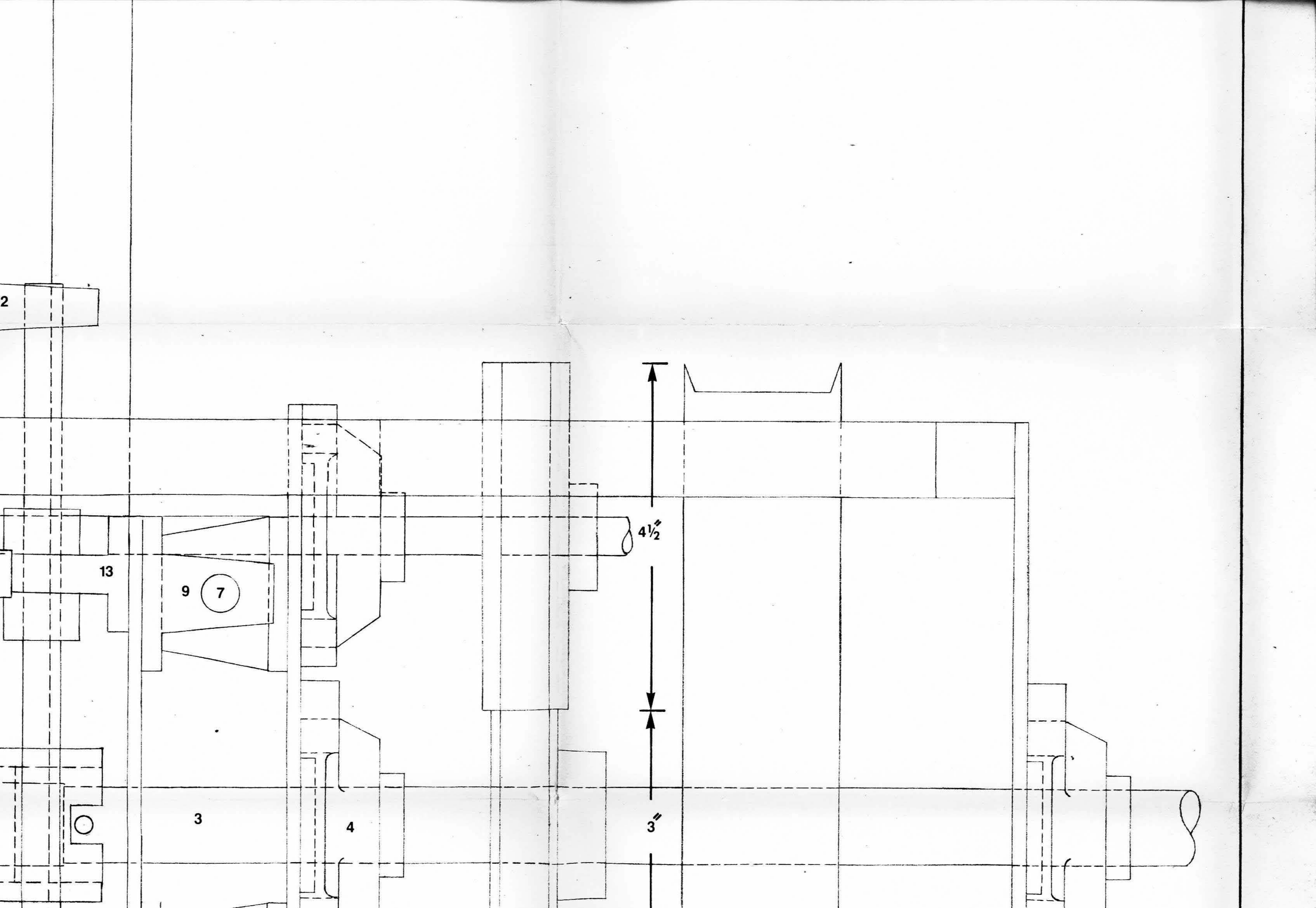
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13
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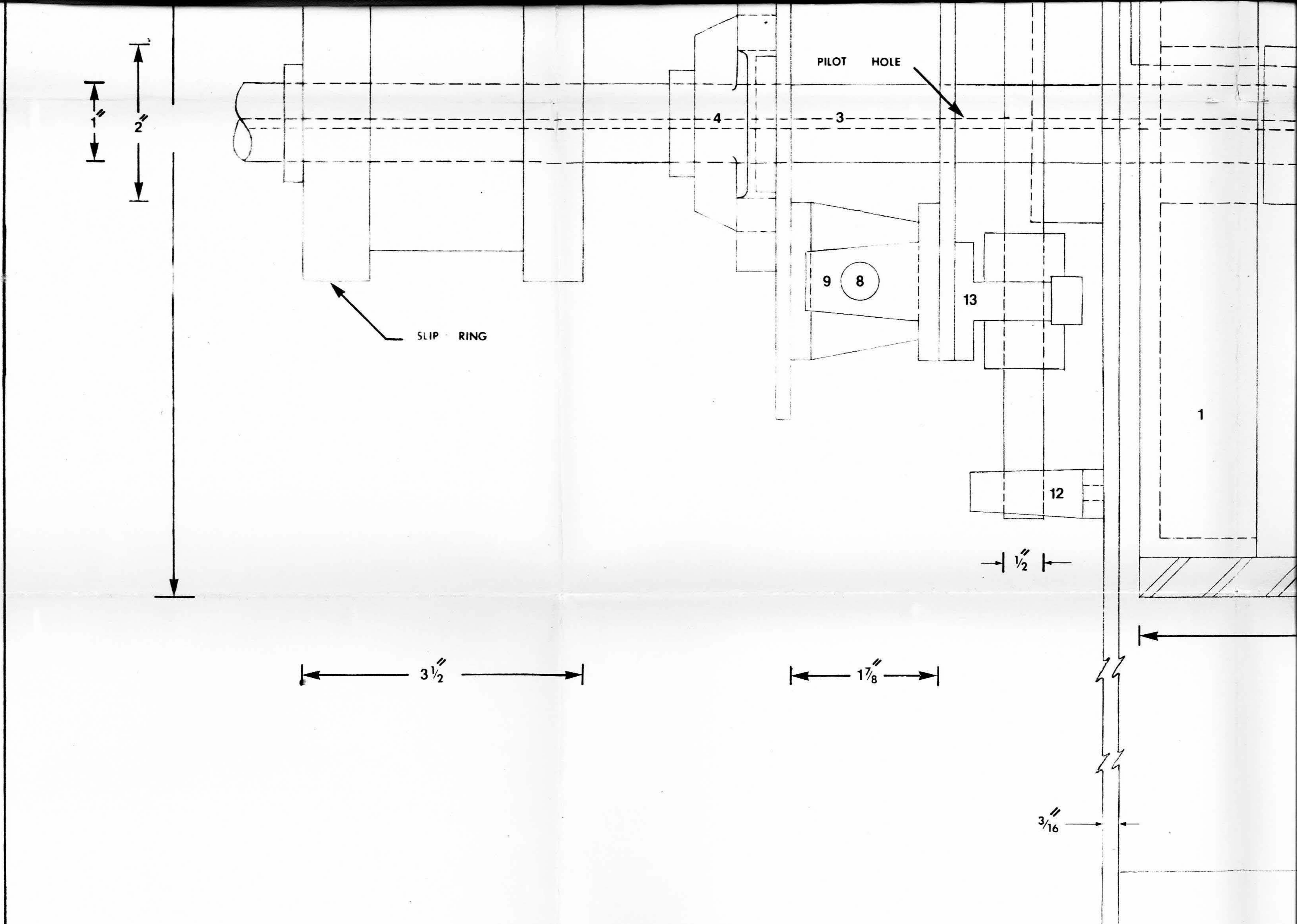
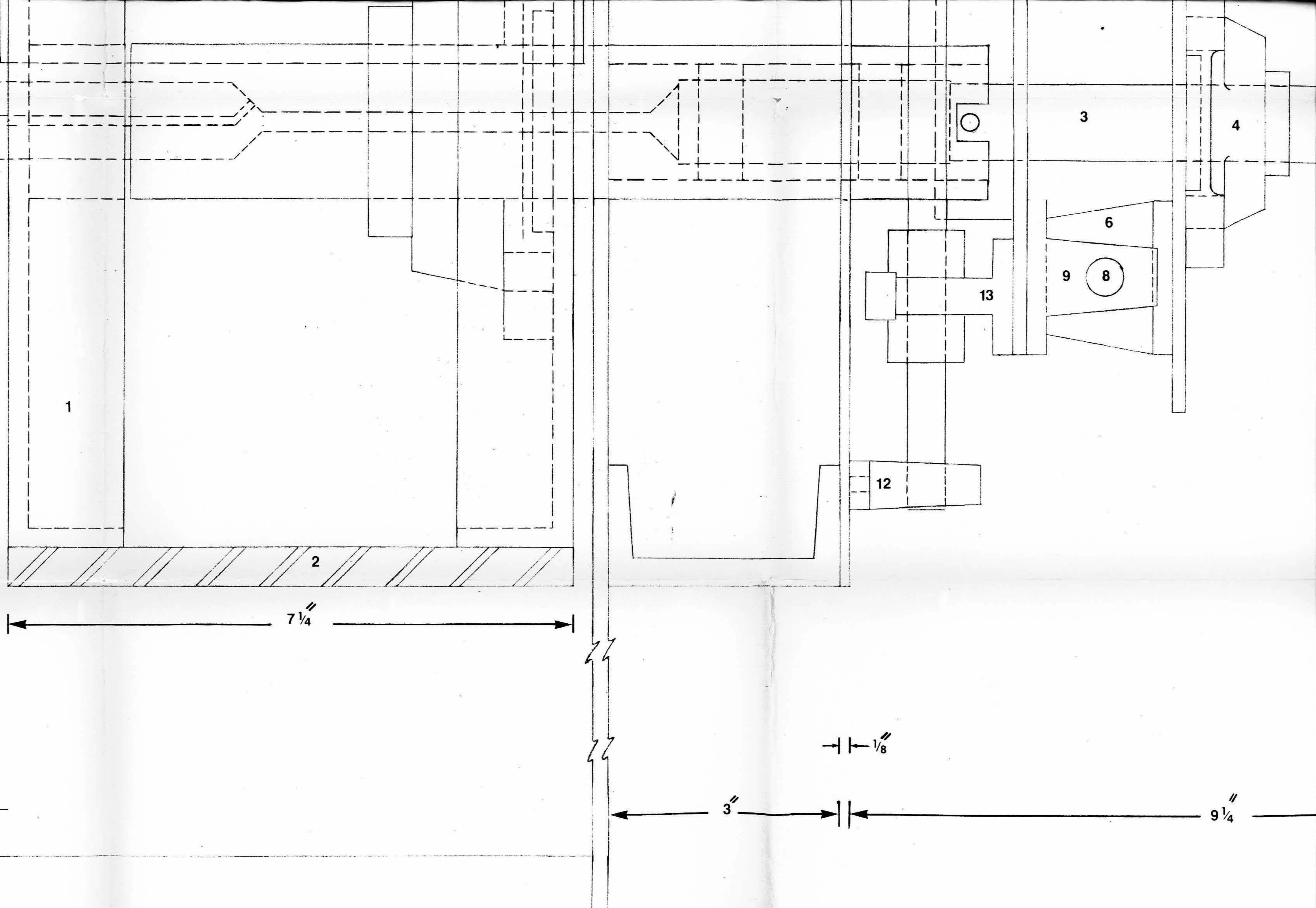
7
4½"
3
4
3"



PILOT HOLE
1"
2"
4
3
9
8
13
SLIP RING
1
12
1/2"
3 1/2"
1 7/8"
3/16



1
2
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8
9
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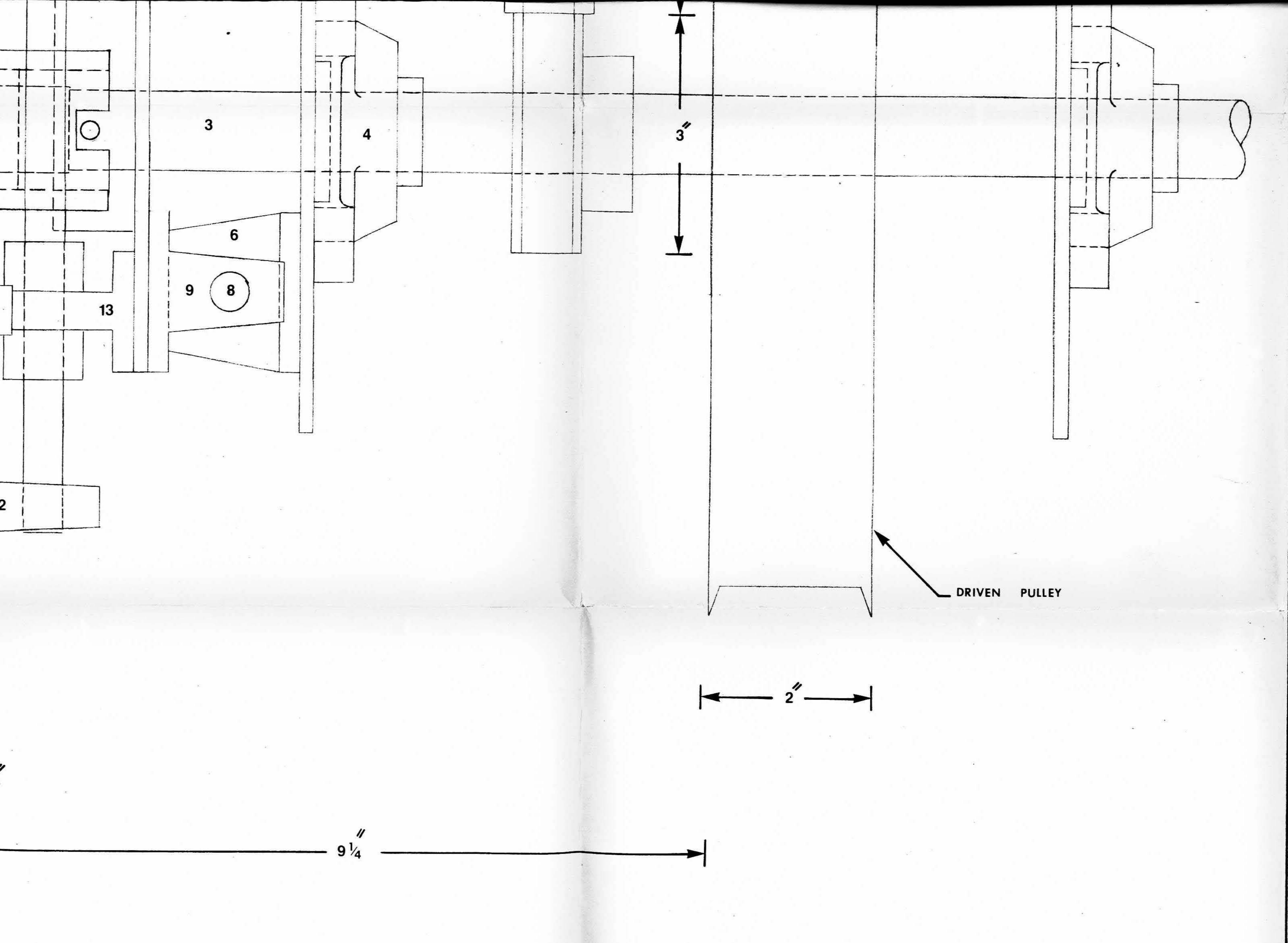
7 1/4″
1/8″
3″
9 1/4″


3
4
3"
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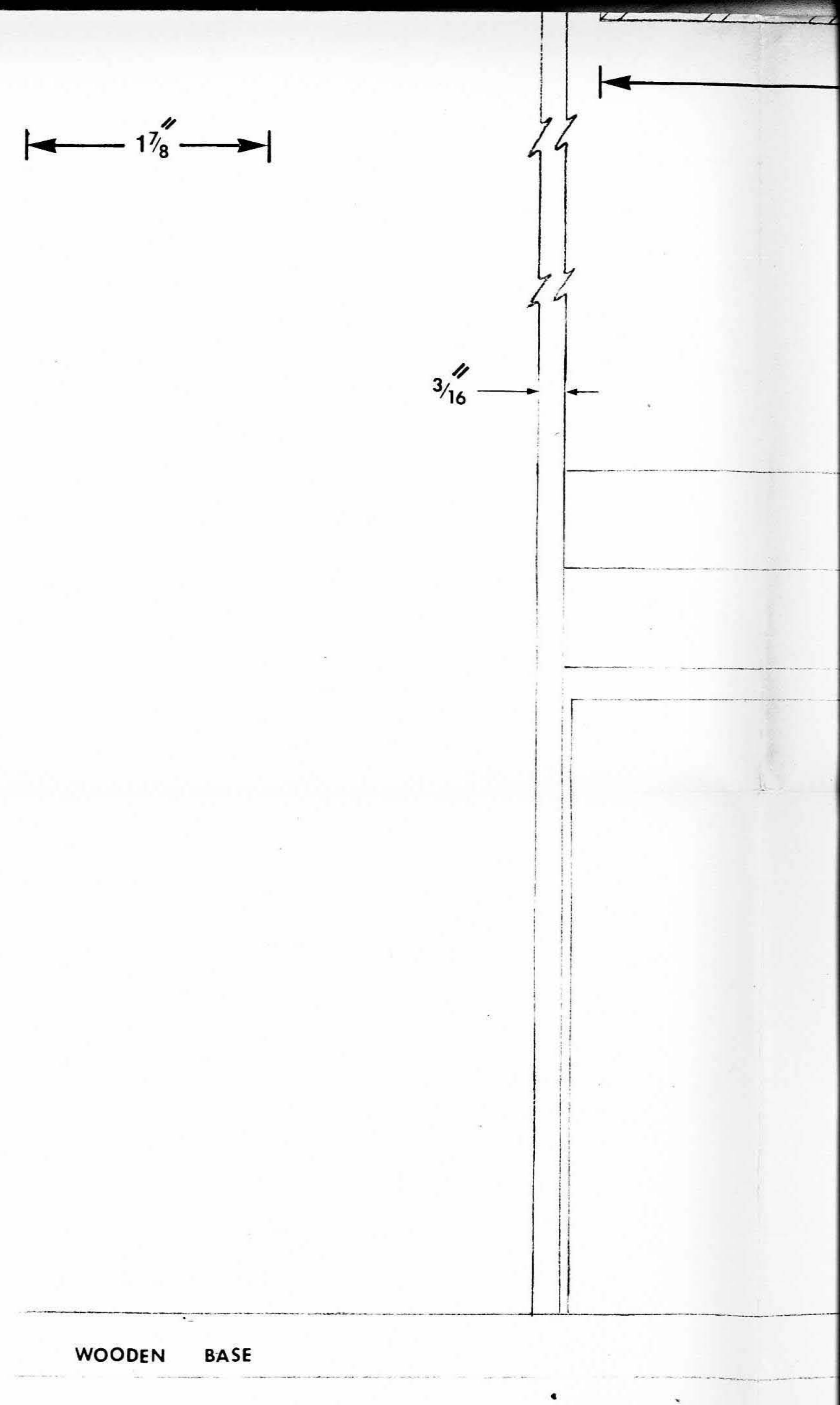
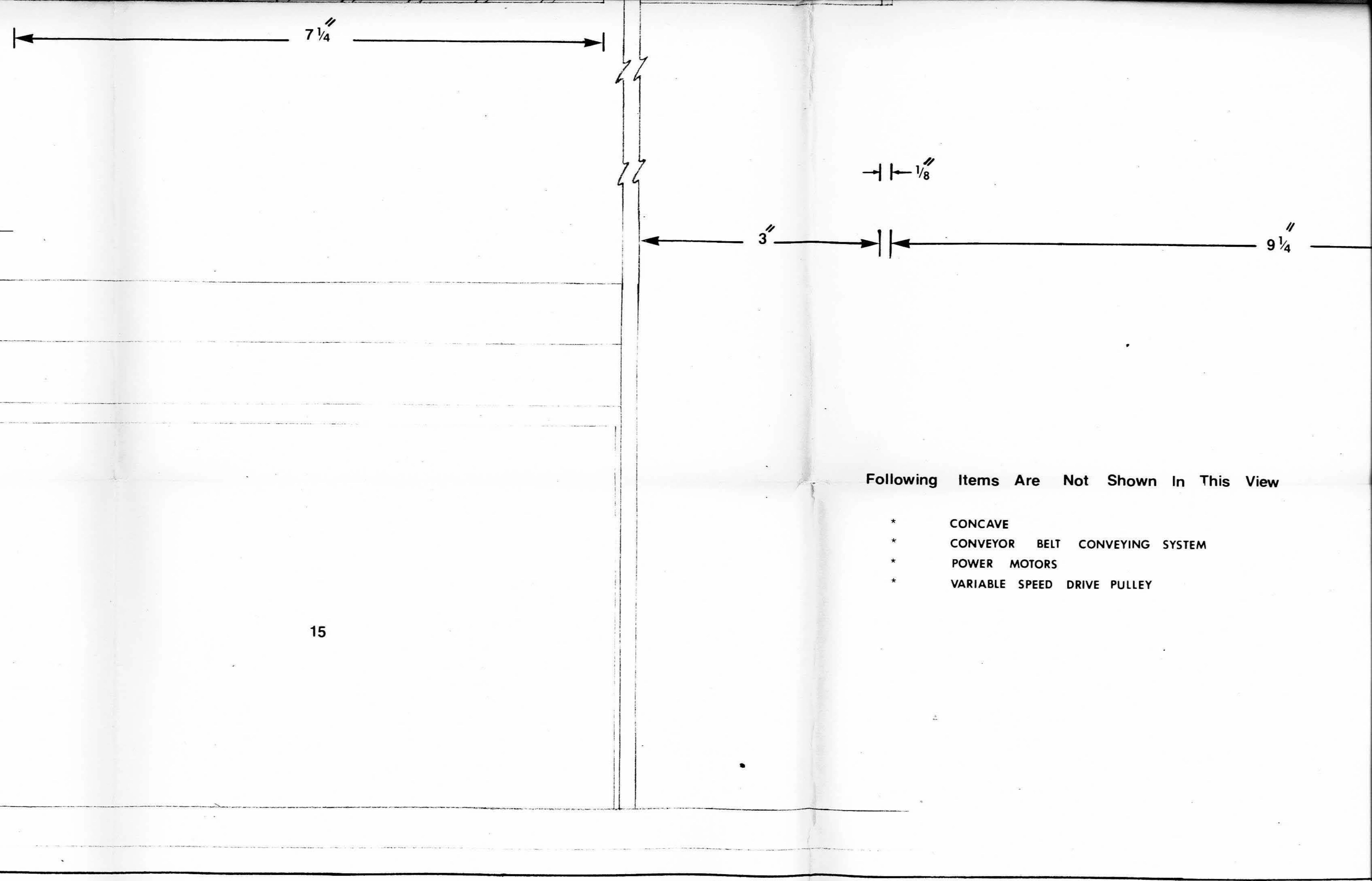
13
2
DRIVEN PULLEY
2"
9 1/4"

3½″



1	CYLINDER DISCS
2	RASP BARS
3	MAIN CYLINDER SHAFT
4	FLANGE BEARINGS
5&10	PLATES
6&13	LINEAR BALL BEARINGS
7&8	60 CASE SHAFT
9&12	SUPPORT BLOCK
11	ADJUSTMENT SCREWS
15	TRAY



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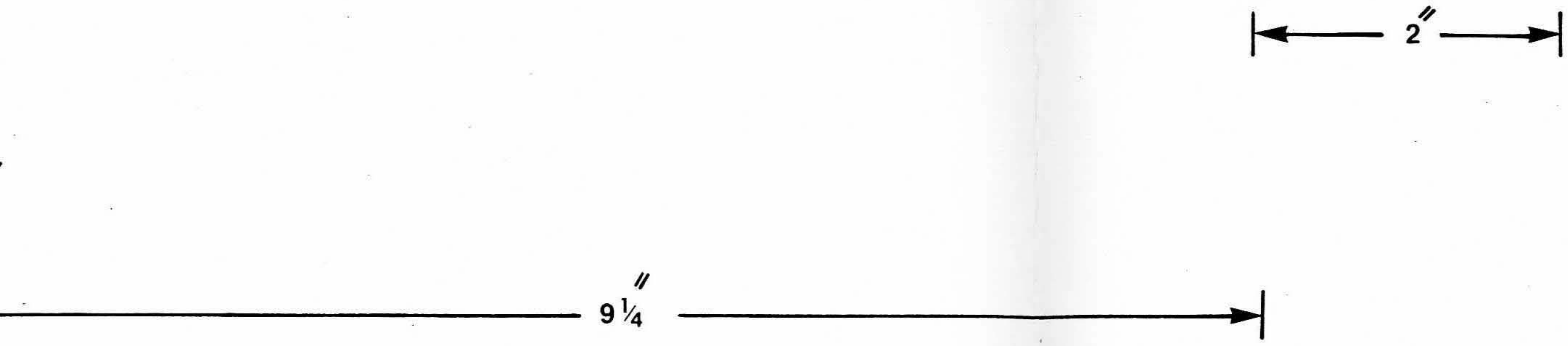
- * CONVEYOR BELT CONVEYING SYSTEM
- * POWER MOTORS
- * VARIABLE SPEED DRIVE PULLEY



g Items Are Not Shown In This View

CONCAVE
CONVEYOR BELT CONVEYING SYSTEM
POWER MOTORS
VARIABLE SPEED DRIVE PULLEY

SCALE : FULL	APPROVED BY S J C	DRAWN BY S H Z
KANSAS STATE UNIVERSITY		
DATE 7. 27. 73		DRAWING 1

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II
2

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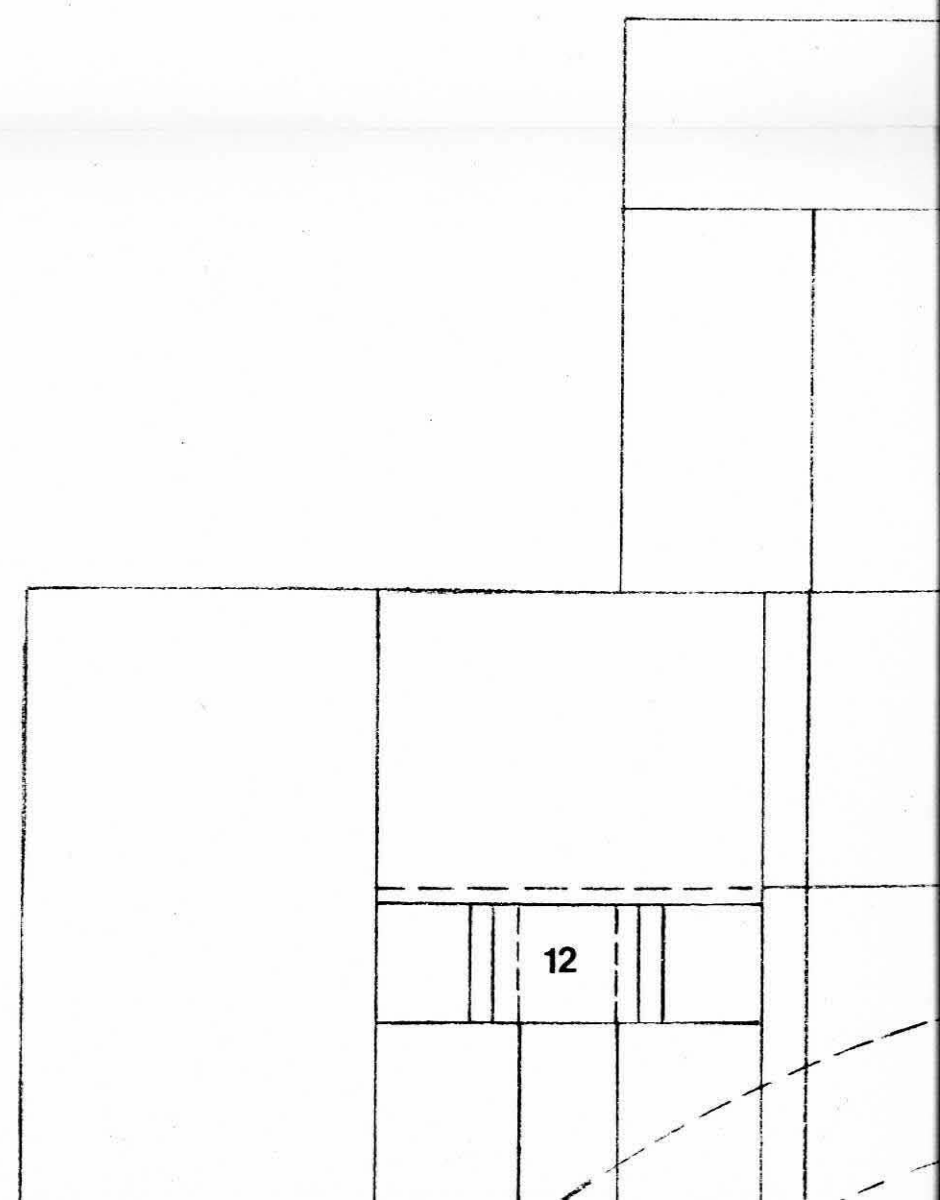
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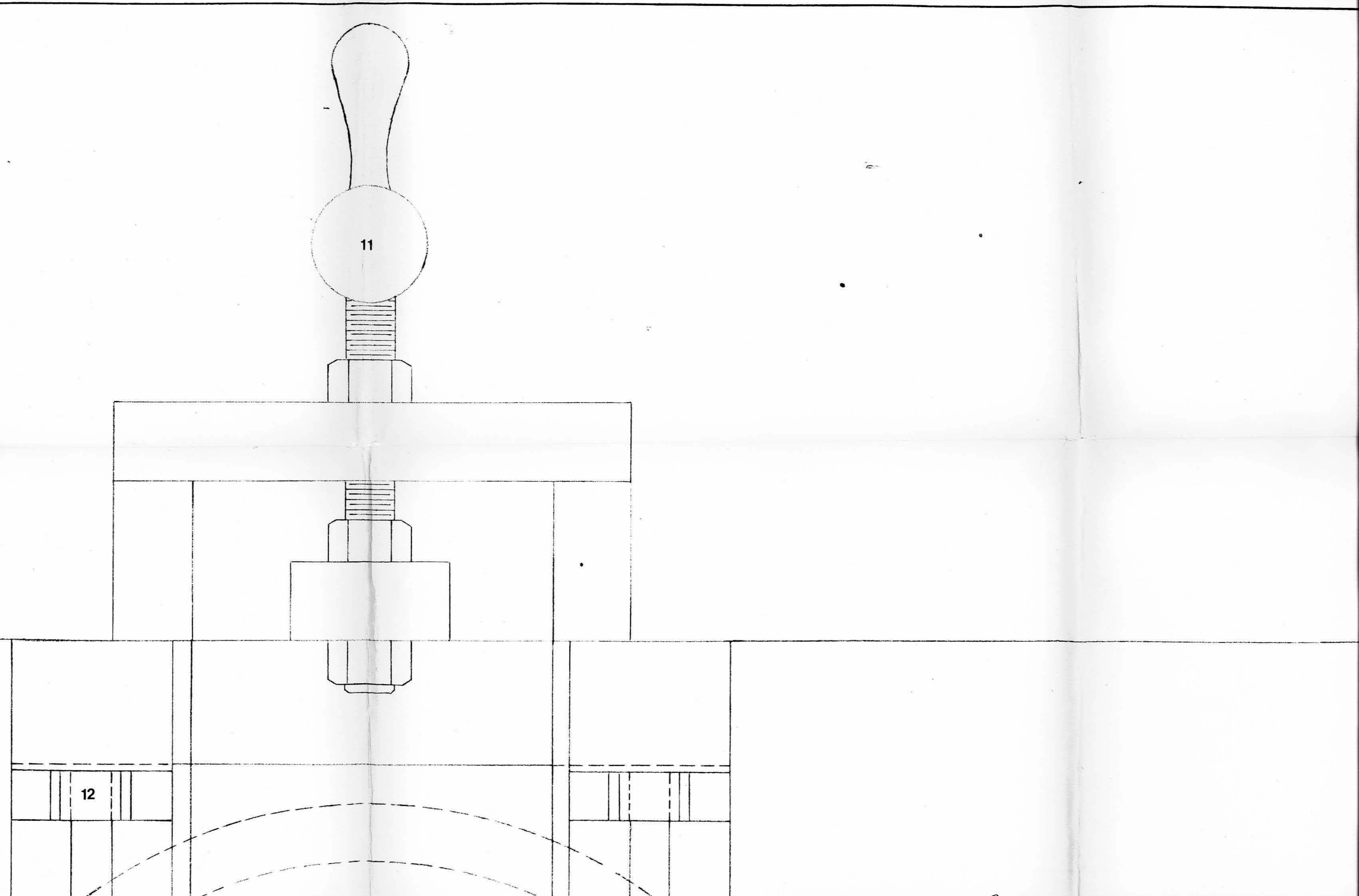

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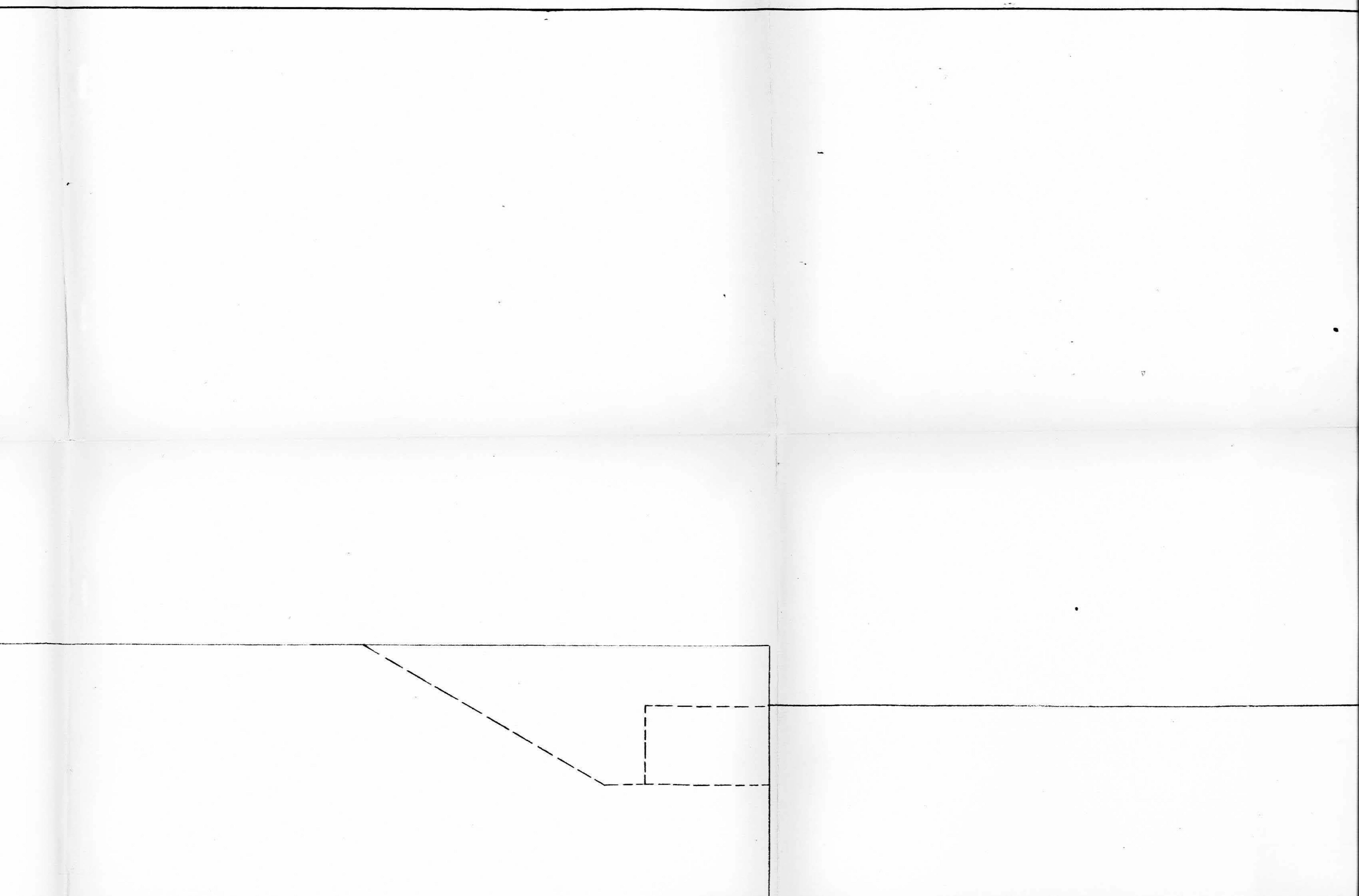
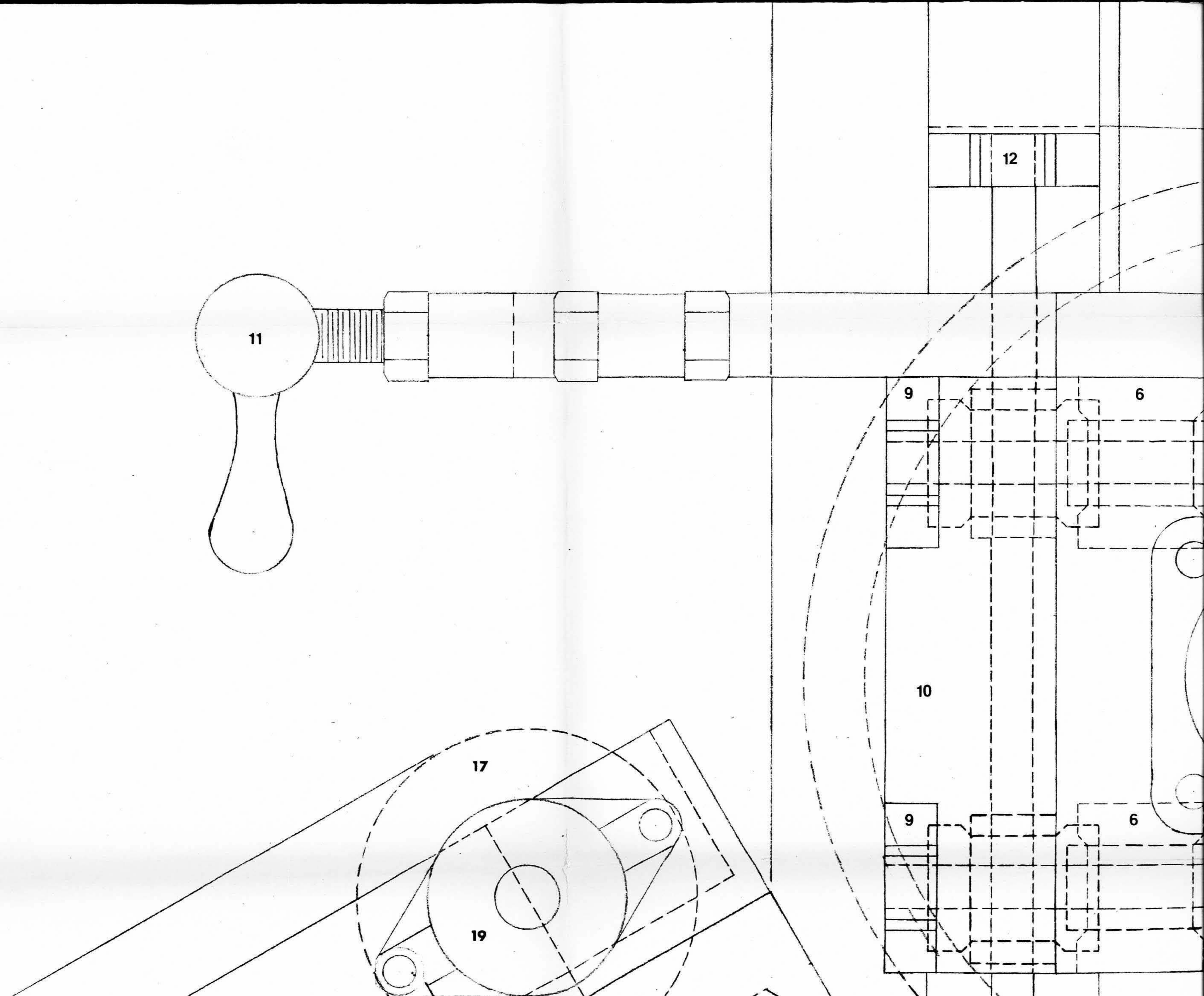


14	BEATER BAR
16	PERFORATED BOX
17	HEAD PULLEY
18	TAIL PULLEY
19	2-BOLT FLANGE BEARING
20	TAKE-UP BEARING
21	TROUGH
22	CONCAVE SIDE SUPPORT



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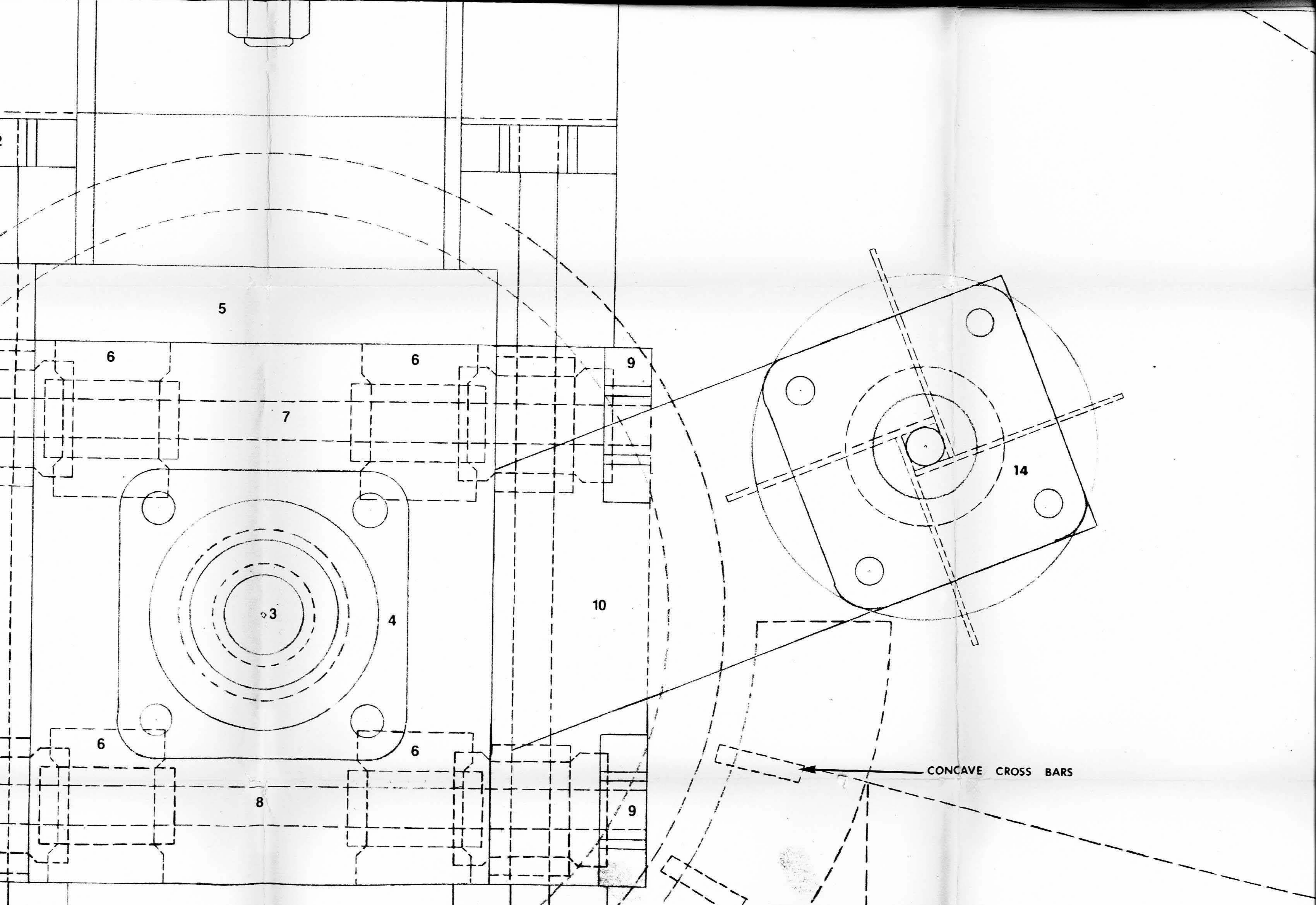

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CONCAVE CROSS BARS
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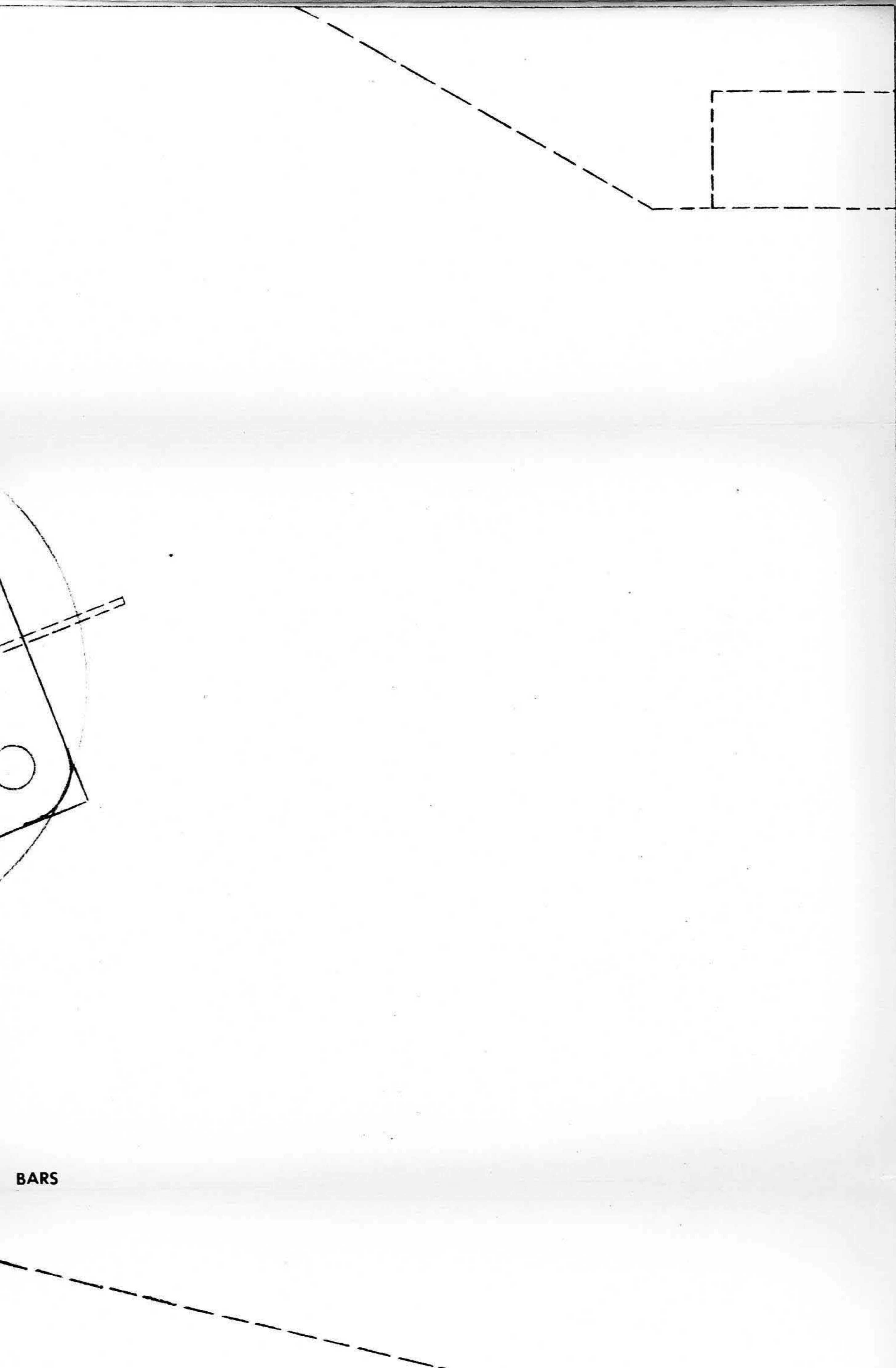

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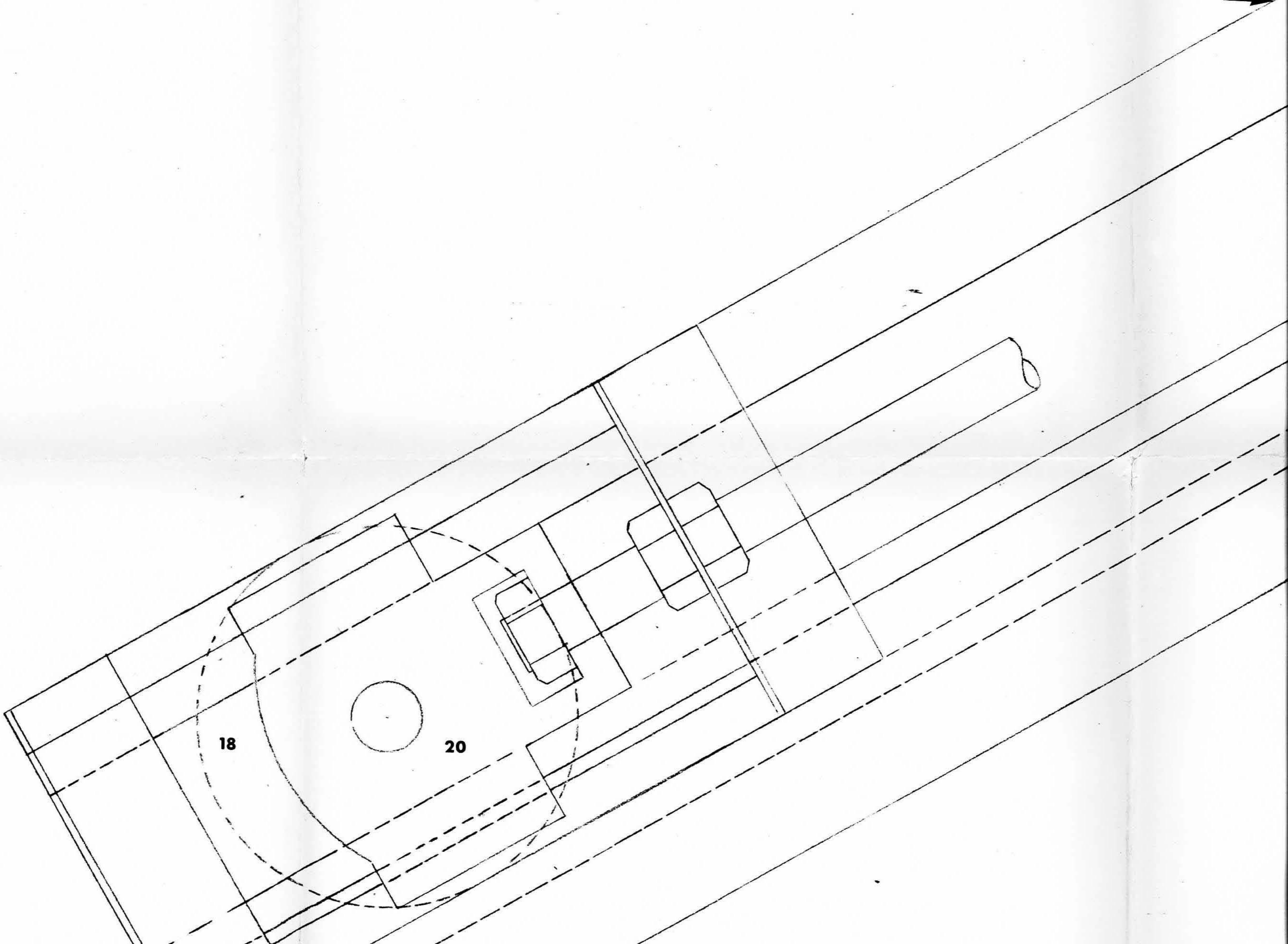
POSITION 7

16

POSITION 7



CONVEYOR BELT
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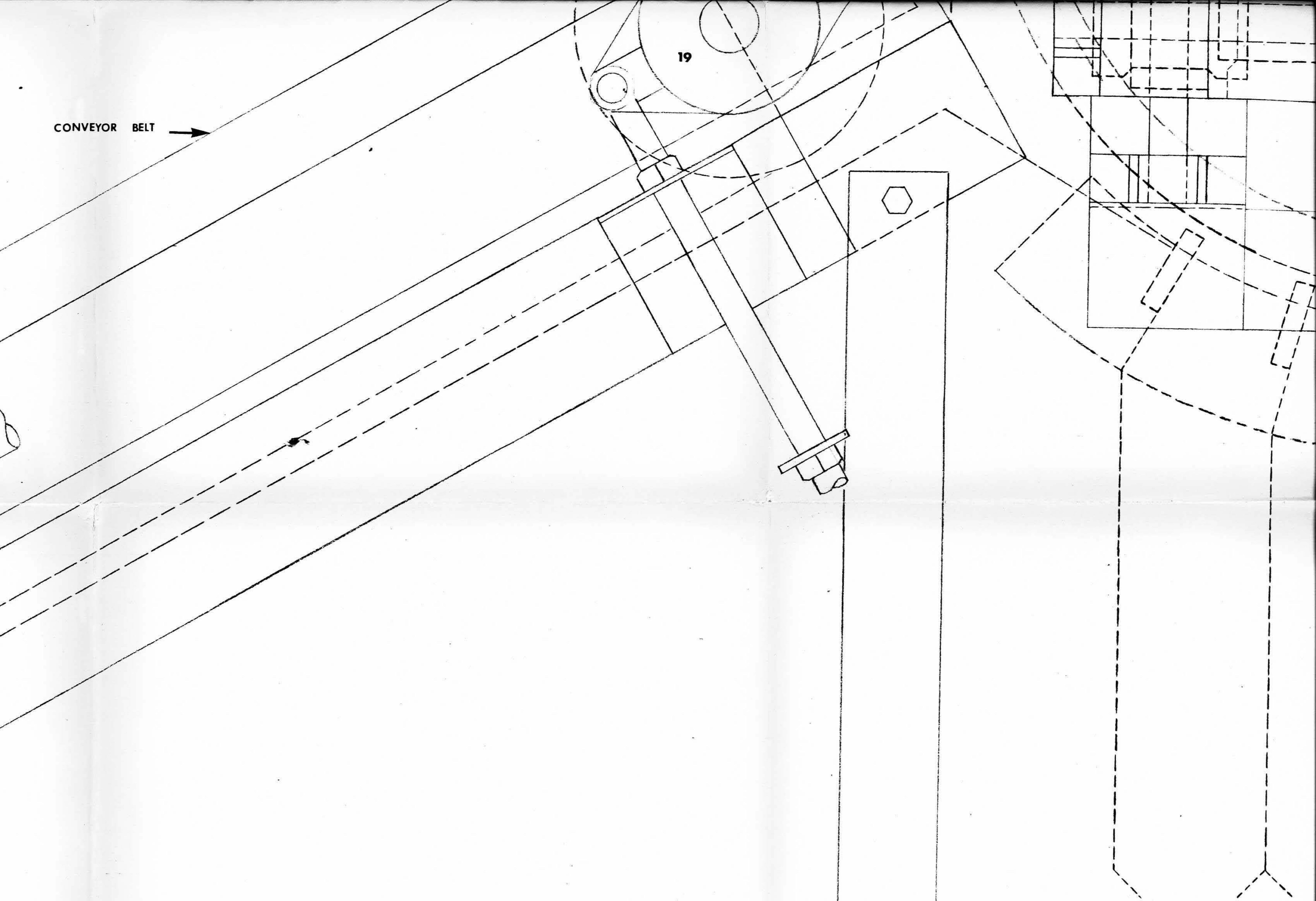
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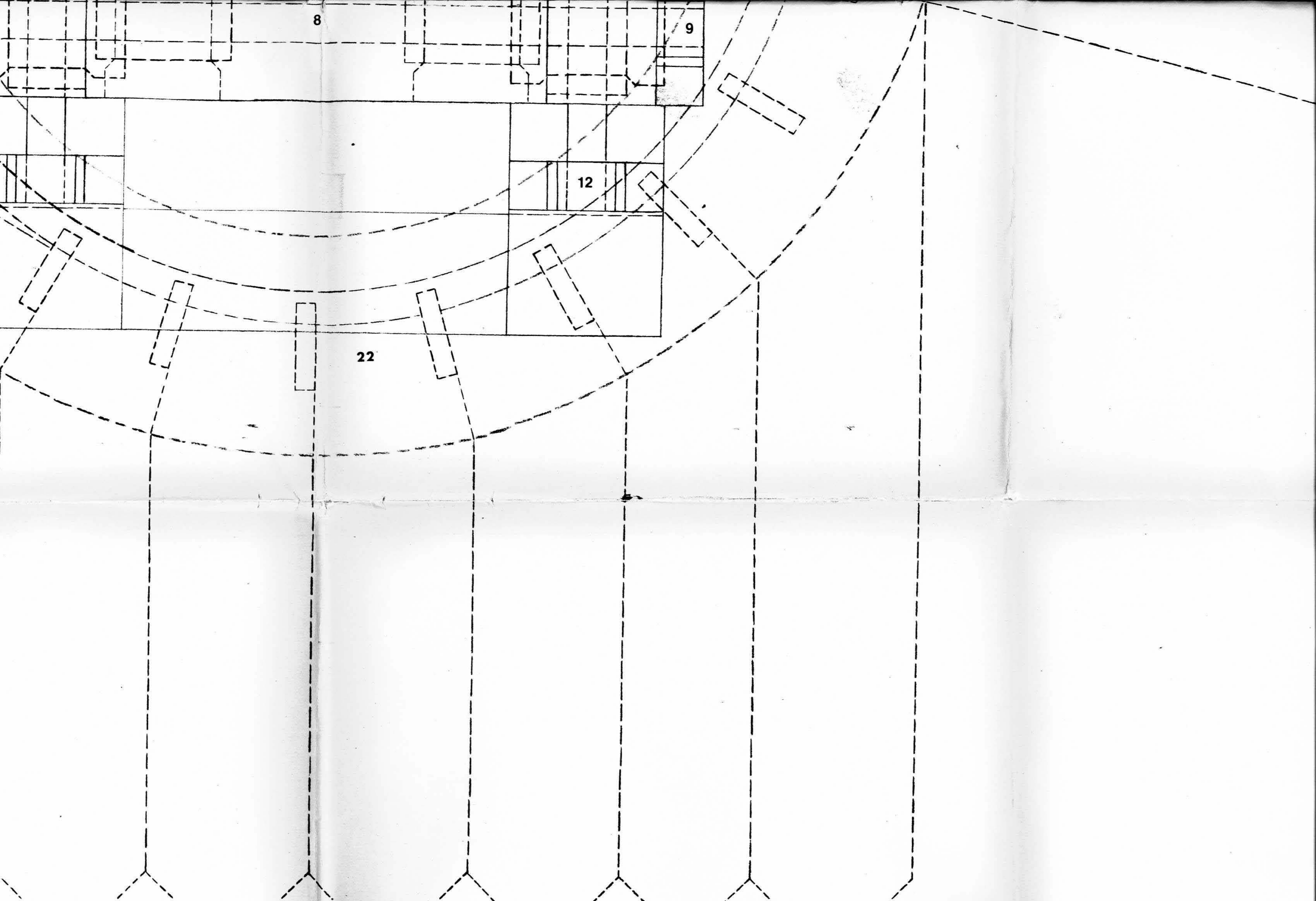
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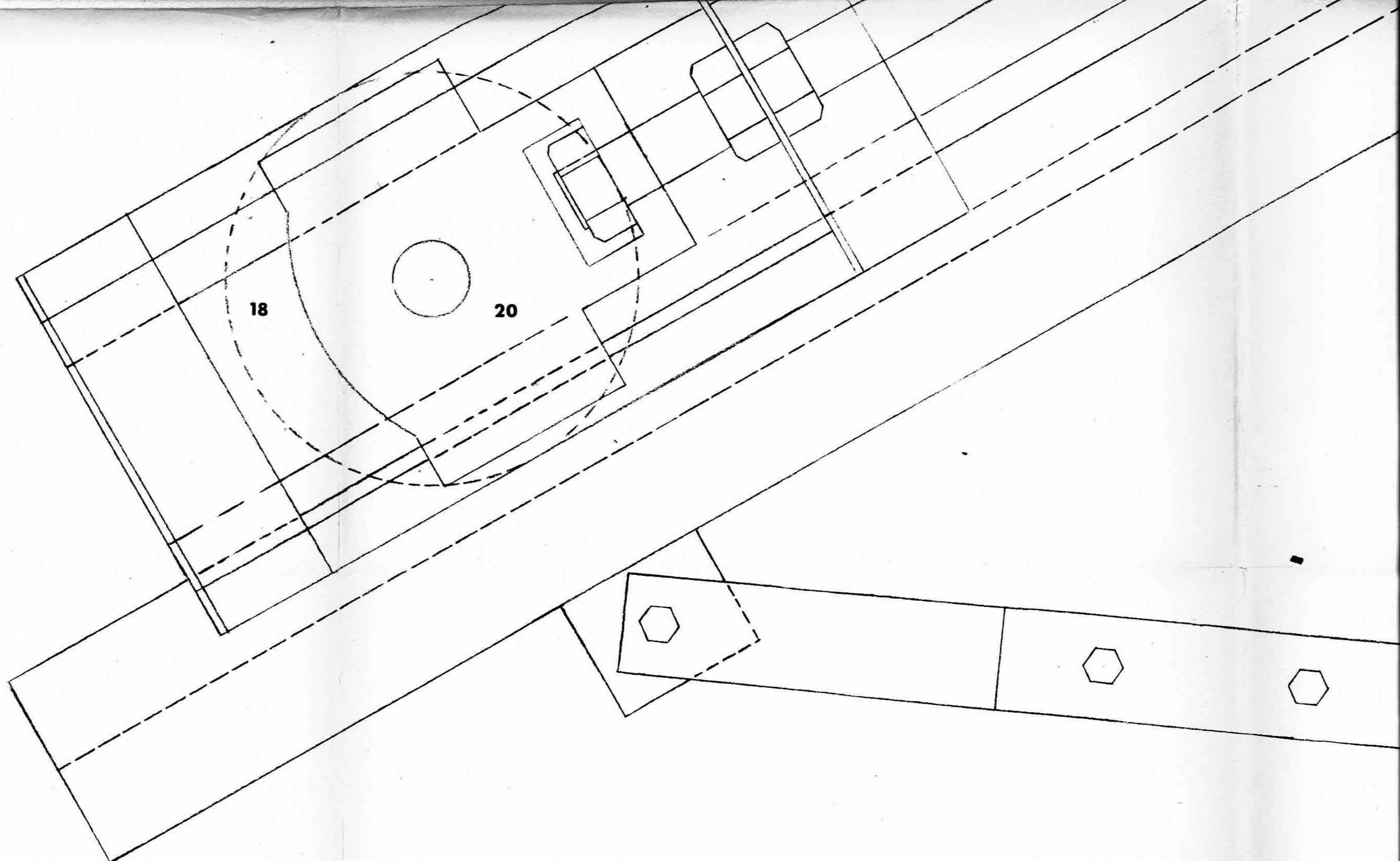
Following Items Are Not Shown In

* POWER MOTORS
* ALL PULLIES
* RASP BARS
* SLIP RING
* TORQUE METER

Following Items Are Not Shown In This View

* POWER MOTORS
* ALL PULLIES
* RASP BARS
* SLIP RING
* TORQUE METER



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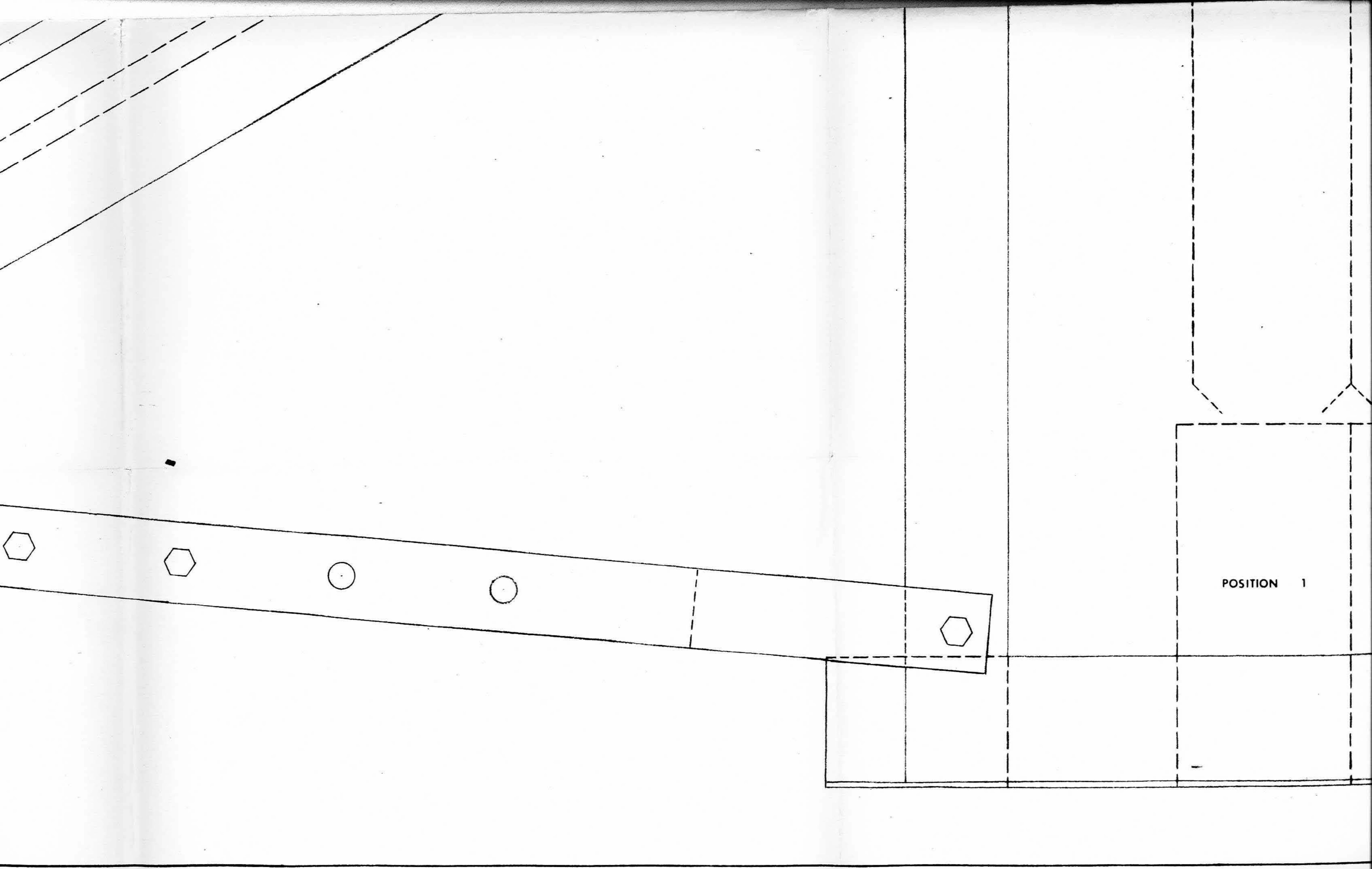
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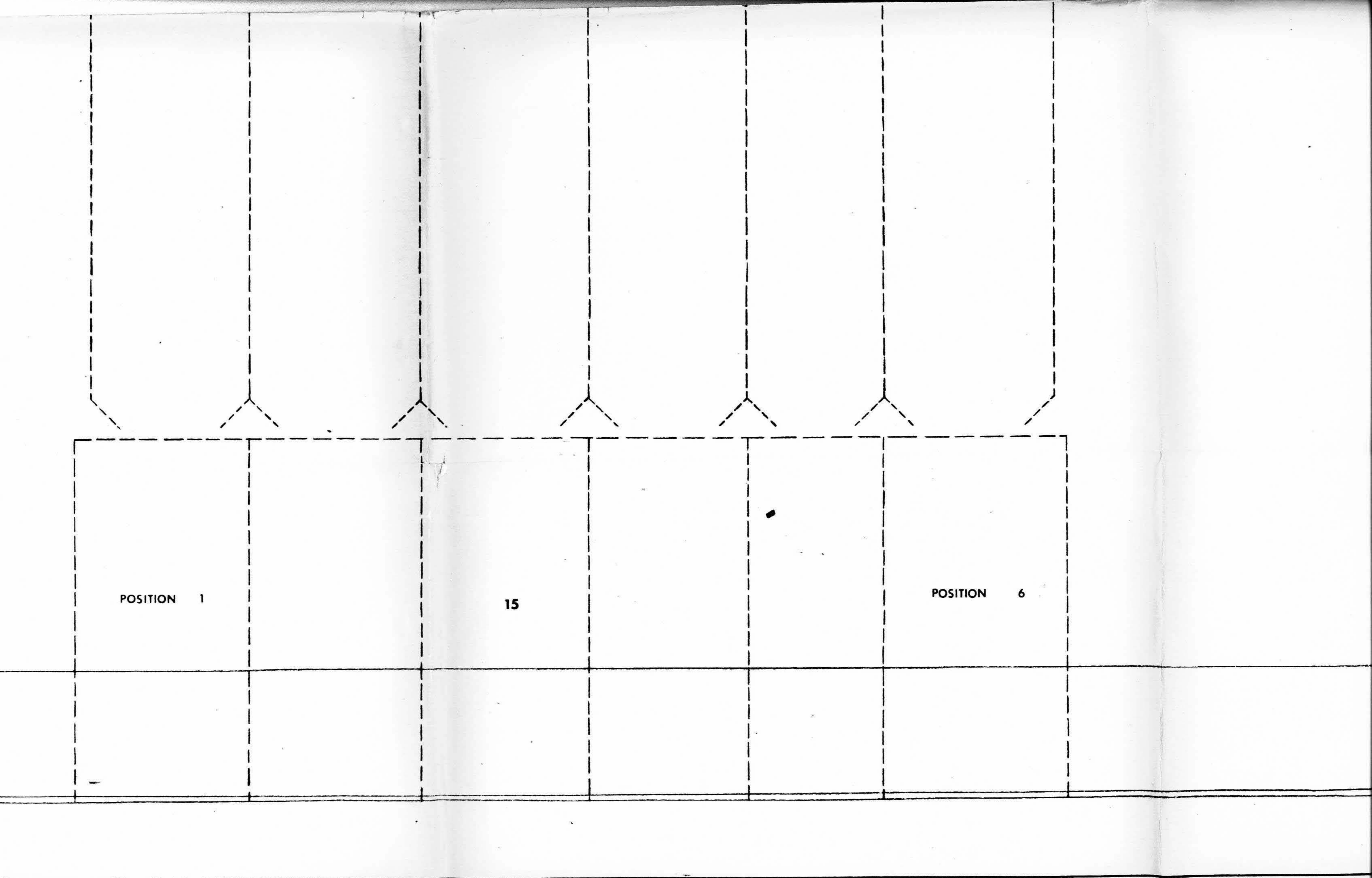
POSITION 1
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POSITION 6

Following Items Are Not S

- * POWER MOTORS
- * ALL PULLIES
- * RASP BARS
- * SLIP RING
- * TORQUE METER

Following Items Are Not Shown In This View

* POWER MOTORS
* ALL PULLIES
* RASP BARS
* SLIP RING
* TORQUE METER

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