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TAPE GUIDANCE STUDY

FINAL REPORT

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ABSTRACT AND SUMMARY

This report describes a research program which was performed to evaluate five different tape guidance systems for dynamic skew and amplitude modulation. The results are as follows:

a. Three systems were within the criteria of 50 microinches peak-to-peak dynamic skew and 10% amplitude modulation. The three systems are:

   1. Internal guidance - System E
   2. Flange guidance - System C 2
   3. Trough guidance - System D 2

b. Magnetic recording tape was measured and evaluated for width variability. There was no significant difference found between commercially slit tape from various vendors. Typical width variations were 0. 000323 inches. When the edges of tape were lapped, the width variability could be reduced to half that of commercially slit tape.

c. The phenomena of average static skew and skew shift were observed and reported on. Average static skew is the component of static skew which is constant, regardless of the direction of tape motion. Skew shift is the direction sensitive component of static skew. Both require skew correction of parallel bits when reproducing data in two directions of tape travel, but not in a

single direction. The range of average static skew found was 0 to 85 microinches. The range of skew shift found was 25 to 200 microinches.

Further testing of the three successful systems with respect to environment and reliability is recommended in order to gain a comparative evaluation of the three successful systems with greater discrimination.

The testing program was conducted using commercially slit tape. Due to the reduced width variability of lapped tape, improvements can be expected in at least two of the systems. This should be a subject of further tests.

INTRODUCTION

Advances in the fields of magnetic recording tape and high resolution magnetic heads have increased the linear packing density capability of digital tape recorders. Linear densities up to 10,000 flux reversals per inch appear within the realm of feasibility, and efforts toward this goal are being pursued. However, when considering a parallel recording system where a character is recorded on the tape in the form of parallel bits across the tape width, the phenomenon of "dynamic skew" places a direct limit on the maximum bit density which may be used in recording systems in which the recovery of data depends on correct synchronization of all tracks.

Synchronization is required in order to recover data in a parallel format because it is necessary to sample simultaneously each bit composing a parallel grouping (character) across the tape. This can only be accomplished if the relative displacement of any track with respect to the clock track is limited to less than $\pm$ 1/2 bit, preferably $\pm$ 1/4 bit as a maximum. Although deskewing techniques have been developed to allow operation with additional skew, considerable system complications are added, including buffer storage and framing references.

Relative displacement of any track with respect to the clock track is primarily a result of non-linear tape motion taking place differentially across the width of the tape. Thus, to minimize differential tape motion, the problem of tape guiding across the read and write heads is primary to the solution of minimizing "dynamic skew".

Tape weave is the second problem which is a result of improper tape guiding. Tape weave is the displacement of tape transverse to the direction of normal motion which results in the recorded bit on the tape not completely overlapping the playback head pole piece. As a consequence, there is a loss of signal level (amplitude modulation), and if the signal level is attenuated below the detection threshold the data is not recovered. The problem of tape weave is more severe when considering a narrow track system. Heads are now available which make possible the recording of 100 tracks per inch. When both the recorded track width and the read head gap width are equal, the signal loss becomes proportional to the amount of tape weave. Such is the system that is being considered in this program.

The objectives of the program were to provide information pertaining to tape guidance, solely utilizing mechanical techniques. The goal was to study various guidance systems which could possibly control dynamic skew to less than plus or minus 25% of the recorded bit length and control amplitude modulation to within plus or minus 10% of the nominal steady state signal level. Meeting these criteria would permit the recording of data at a linear packing density of 10^4 bits in a parallel format on 1/4 inch wide tape. The approach taken in this program was to evaluate six suggested methods of guidance. They are as follows:

1. <u>Single edge guidance</u>

   The nature of this system is to bias the tape to one side so that it makes contact with two rollers, and a continuous edge guide between the two rollers. These two rollers are located on each end of the head assembly.

2. Groove Guidance

This system is based on having tape motion guided by means of a groove in the tape backing which rides on a fixed pair of stylii which are located at each end of the head assembly. The apparent advantage of this system is that if intimate contact is maintained between the groove in the tape and the stylus, transverse motion is limited by the straightness of the groove only.

3. Internal Guidance

This system is based on the principle of tape running on crowned rollers which are located on each side of the head assembly. The principle of crowned rollers is that if a non-slip condition between tape and roller is maintained the crowned roller has a centering effect on the tape which keeps the tape from wandering away from its normal direction of motion. This system also precludes edge wear on the tape thus having a reliability advantage.

4. Flange Guidance

This system is based on having two rollers on each side of the head assembly. Each roller has two fixed flanges, one on the top and one on the bottom. The flanges are positioned so as to maintain a minimum clearance to the edges of the tape. This confines tape motion in both transverse directions at each roller.

5. Trough Guidance

This system has two rollers, one at each end of the head assembly. Like the flange guidance system, it has fixed flanges on the top and bottom of the tape but the flanges are continuous from one end of the head assembly to the other. This has the advantage of guiding tape throughout the head assembly area.

6. Sprocket Guidance

This system is based on having a rotating sprocket wheel on each end of the head assembly. The tape has perforated sprocket holes running down its center line. In this system the sprocket acts as a follower which registers in the perforations of the tape, thus keeping it from wandering from side to side.

The primary goals considered in each guidance scheme were to transport tape across the heads with position control which resulted in linear motion within the head assembly with limits of 50 micro-inch peak-to-peak dynamic skew for a 1/4 inch width of tape being guided in a two inch long guiding assembly. Transverse displacement at the head gaps was to be limited to 600 microinches, which is 10% of the track width. Provisions were made to evaluate the effects of varying the distance between guides if it appeared desirable.

The approach taken in evaluating the six techniques with respect to the goals was to first evaluate the feasibility of each technique by the collection of data and analysis of the mechanical parameters which are pertinent and peculiar to each tape guidance system. Therefore, each scheme would be tested if the preliminary investigation indicated a reasonable chance of success. In the case of sprocket guidance, sprocket tooth alignment and hole alignment in the tape are of primary concern. In the case of internal guidance, crown wobble, and thus ball bearing face run-out, become limiting. The groove guidance scheme was approached on the basis of having the guiding elements static, thus leaving the ability to put a straight groove on the tape and the fit of the guide stylus with the groove as the limiting variables. Evaluation of the potentialities of the edge guidance techniques required that sufficient data be accumulated on tape width and edge straightness variability.

The following discussion is grouped into two main topics:

1. Test equipment and tape investigation
2. Guidance systems development and testing.

BREADBOARD TAPE TRANSPORT

The breadboard mechanism was designed to (1) provide a stable platform to which the various guidance schemes could be tested (see appendix 1 thru 9) and (2) provide the means to transport tape at the various speeds of 0.1 ips, 1 ips and 10 ips through the head assembly area with a minimum disturbance to smooth tape motion which might result from the transport mechanism.

Although the original intention was to provide a mechanism for transporting 1/4 inch wide tape, the transport was designed for 1/2 inch wide tape. This was done because the commercially available 1/4 inch wide instrumentation quality tape was limited in quantity.

To satisfy the two basic requirements, the base plate was made of 1" thick aged "Mehanite" material, which is highly stable. Top and bottom surfaces were ground parallel to each other within 0.0002 inches. The top surface, which is the reference surface, was lapped flat within 2 light bands of interference fringe curvature (less than 25 microinches). All of the rotating transport elements were mounted into jig ground holes which were perpendicular to the top reference surface within 0.0001 inches per inch of perpendicularity.

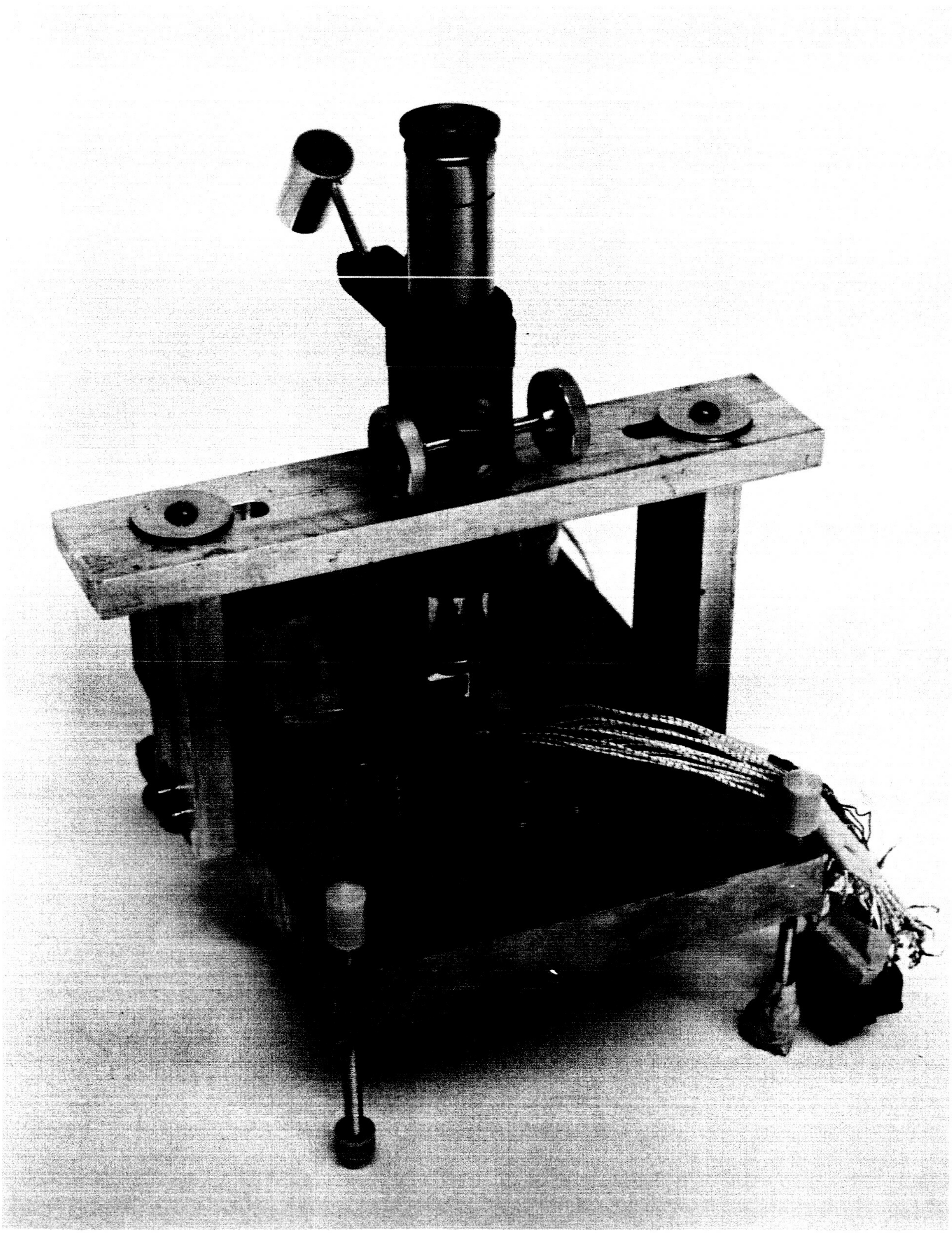
The live shafts (rotating) and the bearings for these shafts were installed directly in the base plate. The stationary shafts with live rollers were mounted by means of precision ground studs which were toleranced for a tight push fit.

All the ball bearings used in the breadboard were procured with a maximum runout of 50 microinches and the high point of the outer race marked. The bearings which were installed in the baseplate (to carry the live shafts) were installed with the high points in line. This orientation was adjusted later to minimize the deviation from perpendicularity. The bearings which were installed in rollers were positioned so that the high point of the outer race matched the low point of the roller. This minimized runout and wobble of the rollers. It was originally planned that all the bearing pairs would be preloaded to one pound preload by a dead weight and the preload would then be retained by a sleeve which was secured to the shaft by a liquid sealant (self-catalyzing). In practice this was found to be an undependable technique. It was found that the liquid sealant would not set up properly if the sleeve fit was free enough to assure the desired preload. This technique was abandoned and the ends of the shafts were tapped to accept #0-80 screws. The preload was then set by the preloading screw so that the axial motion of the bearing assembly was 0.0003 inches with a one pound axial load. It has been found by experience that this method of measuring preload results in an assembly that has no free play and still has a low breakaway and running torque.

After the live rollers were assembled and preloaded, they were all checked for runout and wobble (for this test, wobble was the more critical deviation). One set of rollers had a wobble (high points 180° apart) of 0.0002 inches; the remainder were under 0.00006 inches.

It was desired to hold and measure the deviations from perpendicularity of the tape guide rollers and posts to values which were comparable to the accuracy of the inspection equipment which was available. Special measuring techniques were employed to cancel the deviations of the inspection equipment. A temporary mark was placed on each live shaft or roller. All measurements for perpendicularity were then made in line with this mark. The baseplate was then mounted on an angle plate so that the shafts and rollers were horizontal. The relative levels of the inboard and outboard ends of all the shafts and rollers were then measured with an electronic indicator capable of resolving 10 microinches. This operation was performed four times with the four orientations of the baseplate. Under these conditions the deviation from perpendicularity in one plane is obtained by the average of the two readings taken in that plane. The deviation of the inspection equipment (e. g., the angle plate) adds to one reading and subtracts from the other reading and is thus cancelled out in the process of averaging. The mark previously placed on the shaft or roller was kept on top while each of the four sets of measurements were made so that any eccentricity or taper in the shaft or roller would cancel out in the same way as the angle plate deviation. The perpendicularities of all the shafts and rollers were verified by the above technique, as were each set of tape guides as the individual guidance systems were installed. In some cases the bearing outer races were rotated to reduce the deviation from perpendicularity of live shafts or the wobble of rollers.

A 60 power measuring microscope which can be seen in Figure 1, was installed on the mechanism so that the tape and the tape guides could be exzmined during setup and while in operation. The microscope can be shifted in a plane parallel to the baseplate over the entire area of interest. The line of sight is turned 90° by the use of a prism so that the view is parallel to the baseplate. It is then possible, by shifting the prism and the microscope, to view any level from just above the surface of the baseplate to above the upper edge of the tape. A wide variety of directions of view were possible by rotating the prism. This combination of adjustments made it possible to view all the areas of interest. A reticle in the microscope (graduated in 0.0001 inch divisions) was available to measure small clearances and motions. In practice the variable orientation of the image was confusing, and it was sometimes difficult to be certain of the exact point viewed. This problem was solved by projecting a beam of light (from a pen-type flashlight) backwards through the microscope so that a spot of light on the object would show the field of view. It was then possible to shift the microscope or the prism so that the illuminated spot was at the point to be viewed. It was originally conceived that the primary purpose of this arrangement would be to measure the transverse tape motion as the tape was run in the different guidance systems. This proved to be impractical since the short term variations in the tape width were larger than the motions it was desired to detect (350 microinches). It is easily possible to differentiate 200 microinches with this microscope.



Breadboard Tape Transport

Figure 1

TAPE WIDTH DETERMINATION

After the tape transport and guidance systems had been designed and released for fabrication, tape width variability became the next concern. A survey of the manufacturers of magnetic tape had failed to reveal any information on the width variability within a single reel or between reels. The only information available was that the width was within the standard tolerance (plus 0.000 minus 0.004) and the straightness was such that a ten foot length laid out flat would not deviate from a straight line by more than 1/8th inch. This information was not quantitative and could not be used to predetermine the tape guide width. It was then decided to design a tape width measuring gauge.

TAPE WIDTH MEASURING APPARATUS

A tape width gauge was developed to measure the width of one-half inch wide tape to the desired degree of precision and sensitivity (See Fig. 2). The Gauge consists of a trough of uniform known width and a measuring microscope. With this gauge it is possible to measure the width of tape at any point on a five inch length with a sensitivity of 25 microinches and a precision of better than 50 microinches.

To account for the fact that the tape to be measured might have a curve induced in it during the process of placing it in the measuring

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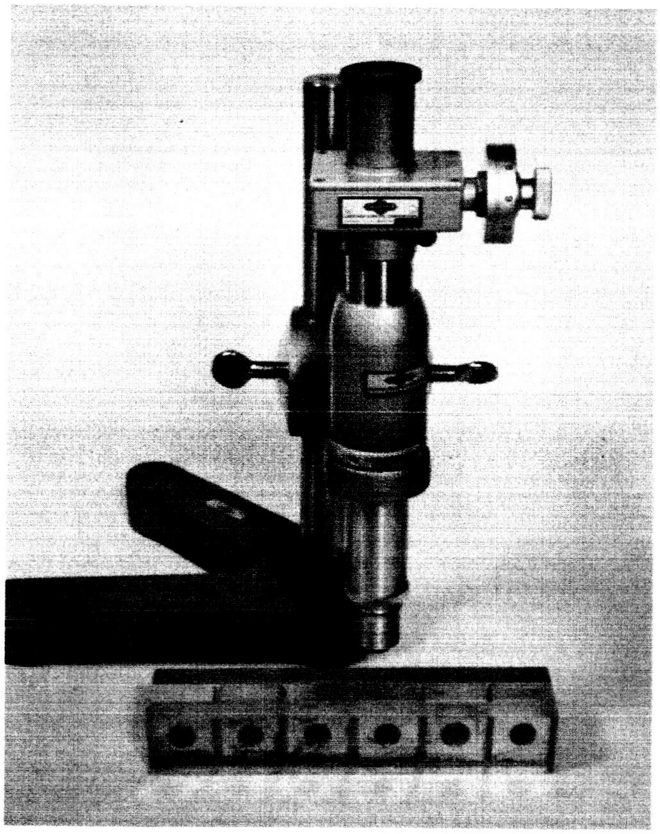


Tape Width Measuring Apparatus

Figure 2

trough, an anlysis was made. This analysis indicates that this is at best a second order effect and can be neglected. The maximum edgewise bending stress that can be induced is limited by the friction force of the tape so that:

$$S = \frac{mc}{I} = \frac{\frac{.00162}{6} \times .25 \times \frac{2}{16} \times .25}{.5^3 \times \frac{.001}{12}} = .2 \text{ psi}$$

where:
- S = Stress
- m = Bending moment
- c = Distance from neutral axis
- I = Moment of inertia

The radius of curvature would then be:

$$p = \frac{Ey}{S} = \frac{7.5 \times 10^5 \times .25}{.2} = 9.4 \times 10^5 \text{ in.}$$

where:
- p = radius of curvature
- E = Modulus of elasticity
- y = Deflection

In a six inch length, the deviation would be:

$$\theta = \text{Sin}^{-1} \frac{6}{9.4 \times 10^5} = \text{Sin}^{-1}\ 6.4 \times 10^{-6}$$

The offset of one end from the tangent at the other end would then be:

$$\text{offset} = 6 \times \text{Sin}\ \theta = 6 \times 6.4 \times 10^{-6} = 38.4 \text{ microinches}$$

The possible curvature will then be well below the resolution of the measuring system.

The resultant tape width gauge was constructed of two rectangular glass flats and six 1/2 inch gauge blocks. The flats were 1 inch by 6 inches in size and flat within two light bands (approximately 25 microinches). When the fringe pattern between the flats was observed the fringes ran substantially lengthwise so the flats were straight within one light band. The gauge blocks were square style 0.500 long by approximately one inch square. The tolerance on gauge length is plus 6 minus 2 microinches for new gauge blocks of this quality. The gauge blocks were not used previous to this application and were all close to the maximum tolerance. The six blocks were compared in pairs so that they could be ranked in order of size. The technique is to place two blocks on one flat and place the second flat on top of the two gauge blocks. If the two blocks differ slightly in gauge length one edge of each gauge block will poke through the fringe pattern, the inner edge on the longer block and the outer edge on the shorter block. By comparing the various combinations, two blocks at a time, the six blocks were arranged in order so that each block was intermediate in size between the adjacent blocks. This was done to minimize strains on the glass flats when the trough was assembled.

The assembly of the gauge proceeded as follows: two thicknesses of the tape to be measured were trimmed to 3/8 inch width and stacked on a surface plate. A strip of window glass 7/16 x 6 inches was stacked on top of the tape. The six gauge blocks were placed edge to edge along the top of the strip of glass in the above order. The two flats were placed on the surface plate with the flat surfaces toward the gauge blocks and slid together to make a sandwich. The assembly was then clamped together with padded clamps. When the fringe pattern stopped shifting the flats were tight against the gauge blocks and the gauge blocks were tacked to the flats with a few drops of lacquer in the corners. After the lacquer dried the assembly was turned over and shimmed so that the top face was parallel to the surface plate. This assembly provided a trough which was straight within 25 microinches, whose width was less than 20 microinches over 1/2 inch and just deep enough to accept a sample of tape.

When originally assembled, the edges of the flats were polished (clear) and great difficulty was experienced in seeing the corner. These edges were roughened with lapping compound to highlight the corner. A series of marks at one inch spacing were placed opposite each other on the two sides of the trough, and one of the spaces was subdivided into one-tenth inch spaces. These marks were used to guide the measurements as described later.

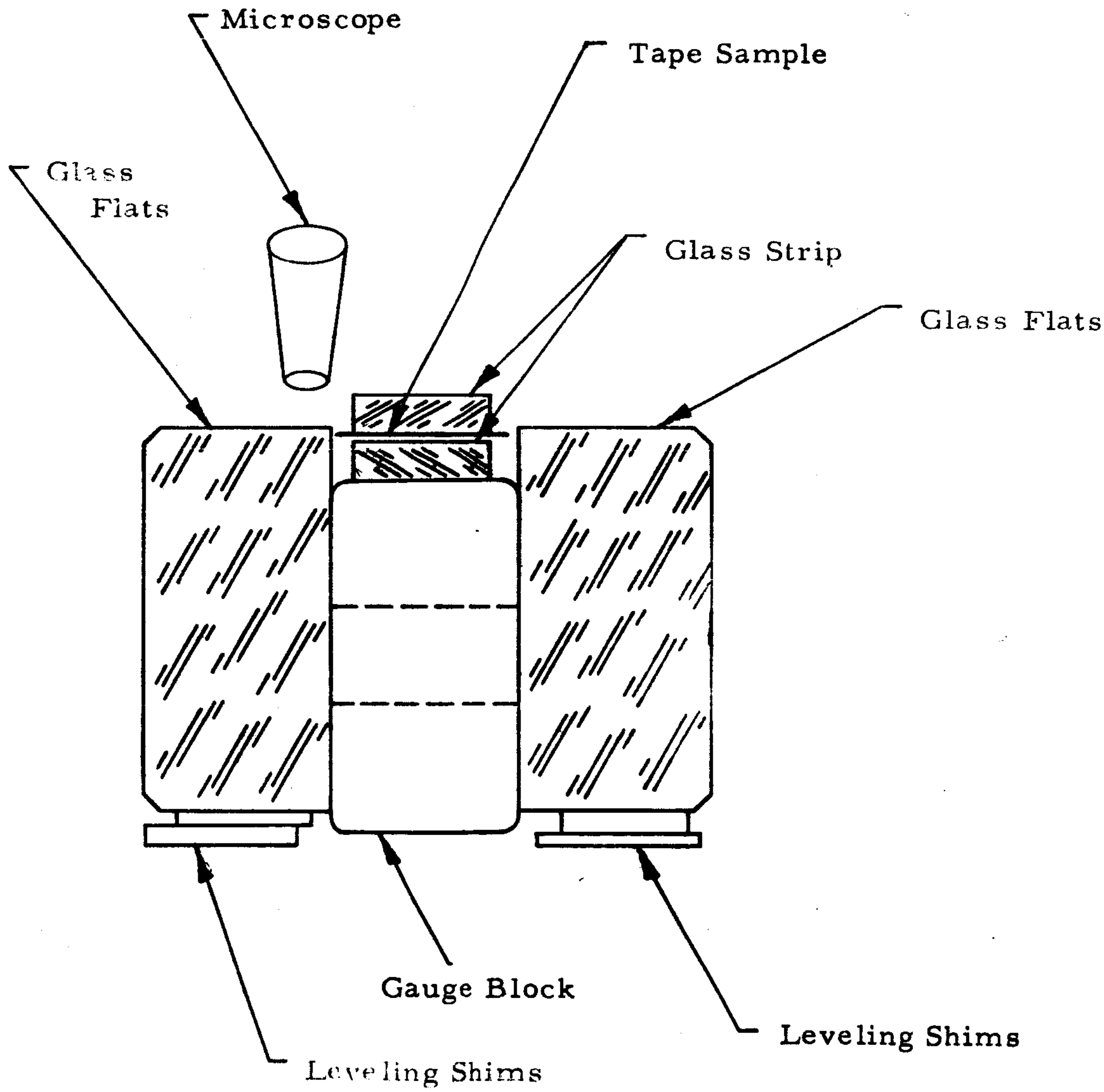
The measuring microscope was of the moving crosshair (filar) type with 100 times magnification. Each division on the drum represents 10 microinches on the object viewed. The depth of field of a microscope at this power is very short. The trough was leveled as described above so that the microscope would require only minor refocusing after being shifted from one point along the trough to a second point.

The trough was braced in position with several lengths of flat ground steel including one length which was 1/2 inch wide. This last length of ground stock was removed when shifting from one side of the trough to the other side.

This in turn simplified positioning the microscope so that the field of view was centered on the gap between the edge of the trough and the edge of the tape being measured.

The resultant assembly (See Figure 3) is a shallow trough which is straight within 25 microinches in 6 inches, exactly 1/2 inch wide and just deep enough so that a sample of tape placed in the trough is substantially coplanar with the edges of the trough. A glass strip was used to hold the tape down. The assembly includes a means for measuring the gap between the sample of tape and the edges of the trough. It was expected that it would be possible to measure the width of the tape by subtracting the two gaps from 1/2 inch, and also to measure the straightness of the tape within the length of the gauge. A number of measurements were made using the glass weight for positioning the tape. Analysis of the measurements gave inconclusive data and non-repeatable data. Consequently the curvature data had to be discarded as inaccurate. However, the width data was valid and was used in establishing accurate width measurements.

The reason it was decided not to utilize the data was because it was determined that the force required to position a piece of tape in the measuring trough induced a curvature into the tape that was greater than the curvatures to be measured. This became apparent while making lapped tape measurements. The initial measurements on the lapped tape showed so little curvature it was decided to overlap the measurements in an attempt to increase the base line.



Tape Width Gauge

Figure 3

Discrepancies in the overlapped portions caused us to recheck the measurement techniques. It was originally planned to lower the tape into the measuring trough so that the tape lay within the trough. In this case, the only tendency to curvature would be caused by the weight of the tape alone. This proved to be impossible in practice. Regardless of the care used, some portion of the tape would lap over the edge of the trough. Also, the tape would not lay flat enough to permit valid measurements. It was necessary to weight the tape to hold it in the plane of the edges of the measuring trough. This was done by means of a narrow strip of glass. Even if the tape had been properly placed in the trough, the glass strip would move the tape as it was put down. The variability was determined and was found to be large enough to invalidate any curvature measurements, but not the width measurements.

It is proposed that with two modifications to the gauges, valid tape straightness data can be gotten. The two modifications are: (1) a gauge trough at least 0.010 inches wider than the nominal tape width; (2) a clamping means which does not shift the tape.

The first can be accomplished by using special size gauge blocks, or stacking two shorter gauge blocks together. The second can be implemented, with an added feature, by substituting a porous plate for the strip of window glass on top of the gauge blocks. The porous plate can then serve as a vacuum chuck to hold the tape in place without transverse forces. A supply of air to the plate then makes the plate an air bearing, and the tape will assume its relaxed shape. When the air supply is cut off and a vacuum applied the tape be firmly held in its relaxed shape while the measurements are made. The porous plate should extend several inches beyond the end of the gauge proper. Centering guides at each end of the trough and higher than the face of the trough would decrease the effort required when setting up the sample. If these features were added to a tape width gauge the width and straightness could be measured within the length of the gauge and the technique of overlapping the samples could probably double the effective length of the gauge.

TAPE WIDTH MEASUREMENTS AND STATISTICS

Ten different reels of tape were measured using the tape width measuring apparatus. Nine of these reels were virgin tape, as received from the manufacturer, and one reel of approximately 500 feet of 3M991 tape was modified. This modification consisted of winding the tape onto a spool narrower than the tape and parallel plate dry lapping the top and bottom surfaces of the pack. The basis on which tape width and width variability was determined was to take sample measurements of each reel. The sample measurements were then used to determine the parameters of mean, standard deviation and variance of each reel of tape.

The method of sampling used was to make measurements in three representative portions of the reel--beginning (B), middle (M) and end (E). Each portion consisted of two adjacent 5-inch lengths of tape. In each 5-inch length, six widths measurements were derived by subtracting the sum of the two edge clearances from the trough width of 0. 5000. The estimates of mean $(\overline{X}_w)$ and sample standard deviation (S_w) were obtained through the use of the following functions which assumes a normal distribution:

$$\overline{X}_w = \frac{1}{n} \sum_{i=1}^{n} X_i$$

$$S_w = \sqrt{\frac{n \sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i \right)^2}{n(n-1)}}$$

The resultant statistics are tabulated in Table 1.

When considering the variances of the nine reels of tape, Cochran's Test for the Homogeneity of Variances was used to decide whether these variances were equal. This test was given by comparing

$$g = \frac{\text{largest } S^2}{S_1^2 + S_2^2 + \ldots S_9^2} \quad \text{to} \quad g_\alpha .$$

The hypothesis that $\sigma_1^2 = \sigma_2^2 = \ldots\ldots = \sigma_k^2$ is accepted if $g \leq g_\alpha$, and S_w^2 is the variance of the tape width.

The derived values are: $g = \dfrac{14.59 \times 10^{-8}}{96.26 \times 10^{-8}} = .152$

At the 5% ($\alpha = .05$) level of significance $g_\alpha = .182$. Hence, the hypothesis is accepted and we conclude with a 95% confidence that there is no difference in the width variability between reels of tape.

Two sections of the lapped tape were measured at the beginning of approximately a 500 foot length. Twenty-six width measurements were obtained and the statistics were derived. (See Table 2). To test whether the variability of the width on lapped tape is significantly less than commercially slit tape, an "F" test was performed which compared the lapped tape variance (S_G^2) to the lumped variance (S_w^2) of the virgin tapes. The critical ratio for significance at 99% confidence ($F_{.99}$) = 2.17. The computed F ratio is:

$$F = \frac{S_w^2}{S_G^2} = \frac{10.7 \times 10^{-8}}{30.6 \times 10^{-9}} = .35 \times 10^1 = 3.5$$

Since $F > F_{.99}$, we conclude that the lapped tape is significantly better.

All these tape samples had been measured at 1 inch increments along the length. This can be considered a random sample since the 1 inch increments were not held very closely and the starting point of the group of six readings was selected in a random manner. There did remain the possibility that a periodicity of about 1 inch wave length did exist and was giving a false indication. This possibility was tested by measuring at 0. 1 inch increments within one of the above increments on several samples of tape. It was found the standard deviation calculated from this fine spacing was substantially equal to that at the regular spacing and that if the widths for both spacings were plotted to scale the fine spacing followed the shape which was indicated by the 1 inch spacing.

TABLE 1
TAPE WIDTH STATISTICS

Item	Tape Type	$\overline{X}_w$ (in)	$S_w \times 10^{-4}$ (in.)	$S_w^2 \times 10^{-8}$ (in.)
1	Audio Tape LB8A 3665 EP	.49836	3.70	13.69
2	Audio Tape LB8 3665 EP	.49651	3.55	12.60
3	3M 951 17260 (4-5-20)	.49786	2.36	5.57
4	3M 951 17260 (4-5-29)	.49735	2.81	7.89
5	3M 951 19076	.49722	3.26	10.62
6	Memorex 62B 2165-6-1-11	.49757	3.87	14.97
7	Memorex 33 3017B-1-13	.49628	2.98	8.88
8	Memorex 33 3015B-2-16	.49716	3.82	14.59
9	Soundcraft 5BTM 36-1.0	.49756	2.73	7.45

Sums	$E\overline{X}_w = 4.47587$	$ES_w = 29.08$	$ES_w^2 = 96.26$
$\frac{\text{Sums}}{9}$	$\overline{\overline{X}}_w = 0.49731$	$\overline{S}_w = 3.23$	$\overline{S}_w^2 = 10.7$

TABLE 2
WIDTH MEASUREMENTS - - LAPPED TAPE

		G = .5000-W x 10^{-3} (in.)	W (in.)	G^2
Section 1	1	9.45	.49055	89.30
	2	9.40	.49060	88.36
	3	9.49	.49051	90.06
	4	9.25	.49075	85.56
	5	9.30	.49070	86.49
	6	9.35	.49065	87.42
	7	9.65	.49035	93.12
	8	9.25	.49075	85.56
	9	9.10	.49090	82.81
	10	9.30	.49070	86.49
	11	9.20	.49080	84.64
	12	9.40	.49060	88.36
	13	9.20	.49080	84.64
Section 2	14	9.35	.49065	87.42
	15	9.25	.49075	85.56
	16	8.95	.49105	80.10
	17	9.10	.49090	82.81
	18	9.20	.49080	84.64
	19	9.25	.49075	85.56
	20	9.35	.49065	87.42
	21	9.10	.49090	82.81
	22	9.07	.49093	82.26

WIDTH MEASUREMENTS --LAPPED TAPE (Continued)

	G = .5000-Wx10^{-3} (in.)	W (in.)	G^2
23	8.90	.49110	79.21
24	9.30	.49070	86.49
25	9.05	.49095	81.90
26	9.00	.49100	81.00

$\Sigma G = 240.21$ $\overline{X}_w = .490762$ $\Sigma G^2 = 2219.99$

$(\Sigma G)^2 = 57699.84$

$$G_w = \frac{\Sigma G_w}{n} = \frac{240.21}{26} = 9.238$$

$$\overline{X}_w = .500 - .009238 = .490762$$

$$S_G^2 = \frac{\Sigma X^2 - (\Sigma X)^2}{n(n-1)} = \frac{26(2219.99) - 57699.84}{26(25)}$$

$$S_G^2 = \frac{57,719.74 - 57699.84}{650} = \frac{19.90}{650}$$

$$S_G^2 = .0306 = 30.6 \times 10^{-3} \times (10^{-3} \text{in.})^2 = 30.6 \times 10^{-9}$$

$$S_G = \sqrt{3.06} \times 10^{-4} \text{ (in)}$$

$$S_G = 1.746 \times 10^{-4} \text{ (in)}$$

INSTRUMENTATION

The method for measuring skew was as follows: An oscilloscope was synchronized on a signal which had been recorded on a track at the center of the tape. A signal near the edge of the tape was viewed on the oscilloscope. Synchronization of the scope was made on the zero crossing of the recorded waveform of the leading track. The measured value of static skew is the average time displacement between corresponding points on the two waveforms, multiplied by the tape speed. In order to eliminate static skew resulting from head azimuth alignment errors between two heads, only one head was used for both recording and reproducing. This head actually spanned the full width of the 1/2 " wide tape but only had 12 tracks spanning half of the width of the tape (1/4 inch).

The usefulness of a dynamic skew measurement will depend in a large part upon how noise affects the ultimate digital system.

The most important sources of noise which add to the actual skew and make the measured value of skew larger than the physical skew of the tape (in microinches) are listed below.

1. Imperfections in the magnetic coating of the tape, especially non-uniformity of thickness.

2. Dust or dirt on the tape which passes between the head and the tape.

Some less important sources of noise are:

3. Changes in the tape tension and flutter and wow.

4. Amplifier noise.

5. Synchronization noise

Imperfections in the tape coating will cause signal amplitude changes resulting in an apparent phase shift in the signal being viewed on the oscilloscope.

Apparent phase changes are also caused by dust or dirt passing between the head and the tape, as well as amplifier noise. Amplifier noise was made negligible by using sufficient shielding such that the signal-to-noise ratio is greater than 40 db. This signal-to-noise ratio was measured with erased tape passing over the head, thus insuring that stray noise is not contributing to amplifier noise.

In general, measurable values of tape tension will not change during a skew measurement, especially in an Iso-Elastic tape drive recorder. However, these tape tension changes are known to be associated with flutter and wow, and will combine with flutter and wow to produce amplitude changes, which in turn will result in scope synchronization errors. There is no known method of isolating the phase changes caused by these sources, and, in general, the effects are included in the skew measurement. However, in order to minimize the effects of flutter and wow, the dynamic skew was measured as the time variation between the point on the synchronization waveform to which the oscilloscope is synchronized, and the corresponding point on the viewed waveform. If later corresponding points are used, the measured values will be greater because of flutter and wow. That is, because the scope sweep speed is constant while tape speed is varying due to flutter and wow, therefore flutter and wow will cause a phase compression or expansion of the viewed waveform. Since the eye cannot subtract the variations of the reference point from the test phase point, the measured value of skew will be greater the further the point of measurement is from the oscilloscope synchronization point.

Synchronization noise is a common defect in oscilloscopes, especially those which do not receive regular maintenance. If there is noise in the scope synchronization circuit, this will result in apparent phase changes due to skew in the method of measurement discussed above. In order to avoid errors of this sort, the scope was tested at the sweep speeds used for skew tests, using a signal generator known to be noise-free. Using a scope hood to shield out extraneous light, it is sufficient to observe whether or not there is any spurious triggering. None was observed.

There is one further precaution which should be mentioned. If the oscilloscope is synchronized on zero crossings, then the signal recorded for this purpose should be a maximum frequency signal. (The viewed signal must be the identical signal, recorded simultaneously with the synchronization signal.) This will minimize the possibility of spurious triggering due to noise. However, the usual practice in a digital NRZ system is to use peak detection in order to eliminate spurious triggering due to noise. In general, skew measured in a peak detection system will be greater than in a zero crossing system at maximum frequency because the derivative of the signal is zero at the peak. Thus, the peak detection system has a wider window during which noise of a given amplitude can cause a synchronization error. In other words, a method synchronizing on zero crossing at maximum frequency will yield a more realistic value of mechanical skew in microinches. However, this value may be slightly optimistic if applied to a digital system using peak detection. The discrepancy will depend upon the frequency components of whatever electrical noise may be present.

SKEW MEASURING

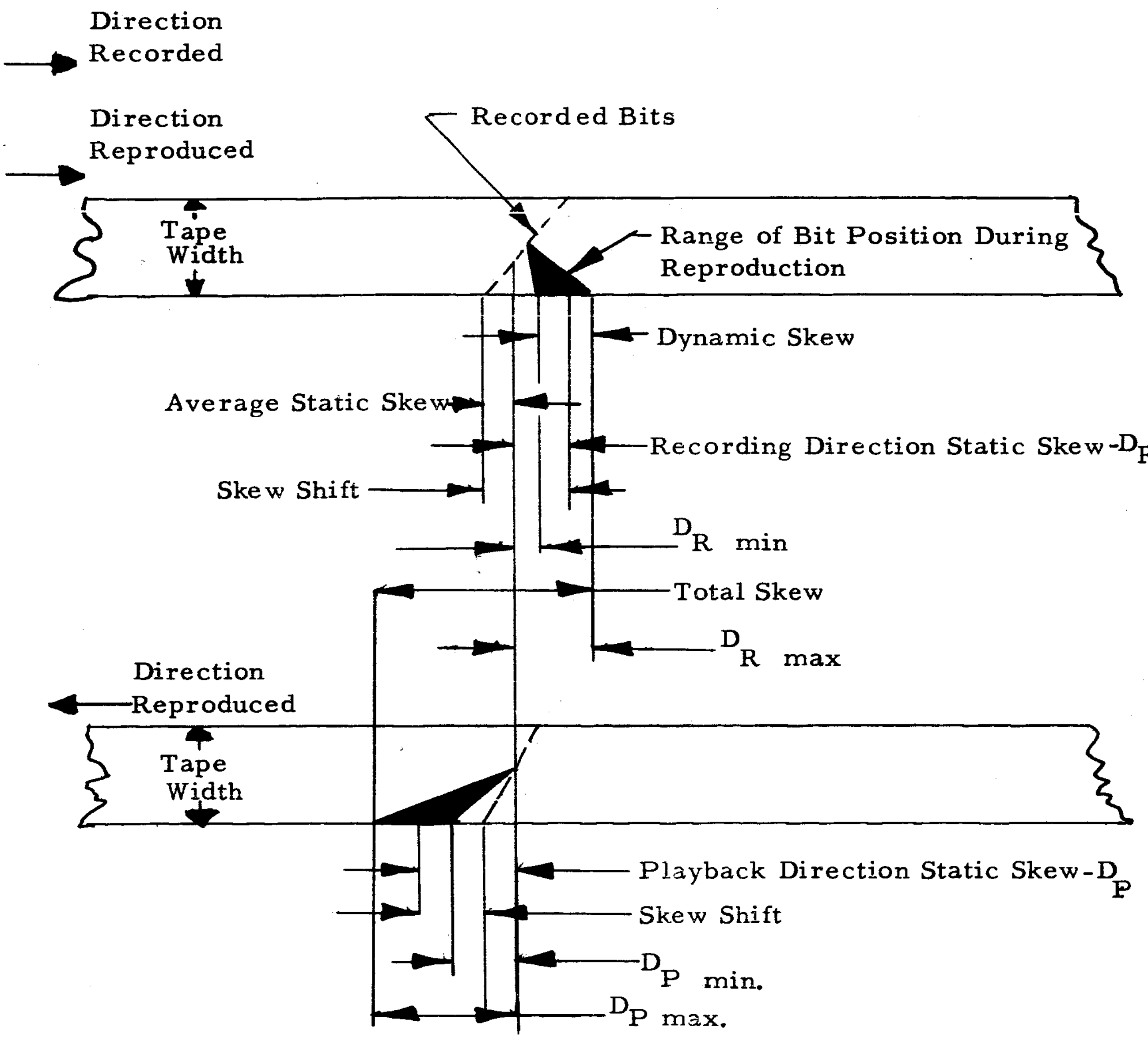
For the purposes of this report the following terms are being defined because no complete set of terms could be found to describe some of the measurements that were made with respect to skew.

SKEW DEFINITIONS

STATIC SKEW:	A systematic displacement between two recorded bits on separate parallel tracks reproduced in a given direction of tape motion. This tape motion may be either in the same or in the opposite direction from which it was recorded.
SKEW SHIFT:	The direction-sensitive component of static skew.
AVERAGE STATIC SKEW:	The component of static skew which is constant, regardless of the direction of tape motion.
DYNAMIC SKEW:	A non-systematic displacement between two recorded bits on separate parallel tracks reproduced in a given direction of tape motion. This tape motion can be either in the same or in the opposite direction in which it was recorded.
TOTAL SKEW:	The maximum systematic and non-systematic displacement between two recorded bits on separate parallel tracks reproduced in both forward and reverse direction of tape motion.

(See Fig. 4 for Skew Diagram)

FIG. 4 SKEW DIAGRAM



1. Total Skew = D_R max + D_P max

2. Dynamic Skew = D_R max - D_R min

3. Static Skew = $\frac{D_R \text{ max} + D_R \text{ min}}{2} = \bar{D}_R$

4. Average Static Skew = $\frac{D_R - D_P}{2}$

5. Skew Shift = $\frac{D_R + D_P}{2}$

SINGLE EDGE GUIDANCE

Description - System C-3

The single edge guidance system as shown in Appendix 5 is based on the principle of forcing the tape to rub on one edge only against a guiding surface. Due to the fact that only one edge of the taper is guiding, it is expected that any transverse motion of the tape will result from the lack of tape edge straightness. The means used to force the edge of the tape to the guiding surface is a taper on each of the rollers which are located on either side of the head assembly. These rollers are spaced 2-1/4 inches apart. The taper on the rollers behaves in the same manner as crowned rollers in a conventional belt system. That is, it forces the belt to travel toward the high diameter. In the case of the rollers in the head assembly the center line of the high diameter is offset toward the guiding surface.

Edge Loading Analysis

The critical edge force of the tape against the guide was calculated by use of formula A, page 312, Roark, Formulas for Stress and Strain:

$$S_{cr} = K \frac{E}{1-\nu^2}\left(\frac{t}{b}\right)^2 = \frac{2 \times 7.5 \times 10^5}{1 - .3^2}\left(\frac{.001}{.420}\right)^2 = 9.34 \text{ psi}$$

The allowable edge loading (w) was set at .0025 lb/in. for a factor of safety of 4.

The allowable edge loading was then used to determine the end rotation of the appropriate portion of tape considered as a simply supported beam with uniform loading:

$$\theta = \frac{w\,l^3}{24El} = \frac{10025 \times .390^3}{24 \times 7.5 \times 10^5 \times 9.56 \times 10^{-6}} = 8.6 \times 10^{-4} \text{ radians}$$

This is equivalent to a conical surface with a generating angle of:

$$\alpha = \frac{\theta}{\pi} = \frac{8.6 \times 10^{-4}}{3.1416} = 2.74 \times 10^{-4} \text{ rad.} = 0^{\circ}\ 00.943'$$

This small taper is impractical to produce and therefore a shorter steeper taper with an equivalent effect was derived.

This full length uniform taper affects the path length over a span of 2.890 inches between points of symmetry so that the unit strain at the edge of the tape differs from that at the center line by:

$$\epsilon = \frac{\delta}{l} = \frac{25 \times 2.74 \times 10^{-4} \times \frac{\pi}{2}}{2.890} = .372 \times 10^{-4} \text{ in/in.}$$

The differential edge strain causes a differential stress which, at the edge is:

$$S = \epsilon E = .372 \times 10^{-4} \times 7.5 \times 10^{5} = 27.9 \text{ psi}$$

This results in a trapezoidal stress distribution which has a resultant offset from the centerline of the tape.

$$\text{Offset} = \frac{2 \times \frac{2}{3} \times .250 \times \frac{27.9}{2} \times .250}{.5 \times 1087} = .0021 \text{ in.}$$

The very small taper indicated above would be very difficult to procure and, therefore, partial taper with equivalent offset of the resultant was derived. An interesting by-product of this derivation is an indication of the parallelism requirements of tape guidance rollers. The partial taper selected was a $1/2^{o}$ per side taper with the length of the taper to be determined. The tape length affected is as above, 2.890 in. The change in tape length due to the partial taper is:

$$\delta = \frac{\pi}{2} \times \tan. \frac{1^{o}}{2} = .0137\ x$$

and the unit edge strain due to the taper is:

$$e_{taper} = \frac{.0137\ x}{2.890} = .00475\ x \text{ in/in/in of taper}$$

The change in stress due to edge strain is:

$$\Delta S_{taper} = \epsilon E = .00475\ x \times 7.5 \times 10^{5} = 3.560\ x \text{ psi/in/in/in}$$

The offset is then:

$$\text{Offset} = .0021 = \frac{3.560\ x \times \frac{x}{2} \times (.250 - \frac{x}{3})}{.5 \times 1087}$$

$$.00193 = .750\ x^{2} - x^{3}$$

$$x = .045$$

This is the calculated length of the taper for the roller guide positioned next to the head. For the position away from the head, the length of taper calculates as approximately the same value as the critical edge loading and just about compensates for the decreased strain.

The position away from the head (2-1/4 in. spacing) was the one used in testing.

Testing - Single Edge Guidance

The initial set-up of this system showed a tilt in the guide rollers of .00015". This caused the tape to ride off the guide plate. The rollers were then modified by increasing the length of taper from .040 to .150 inches at 0.5° taper. A skew test was then made which showed a 20 microsecond skew offset when played back in the opposite direction to which it was recorded. A dynamic skew of ± 40 microinches was measured from the center to the edge of the 1/2 inch wide tape in the same direction as recorded. It was also noted that when a recording was played back in a direction opposite to the direction in which the recording was made, there is a slow skew drift in one direction of 25 microseconds, which is equal to 250 microinches at the 10 inches per second (ips) tape speed at which the test was conducted. The bit packing density for this test was 1000 bits per inch (bpi). Dropouts were also observed on the bottom track only and were attributed to insufficient tape tension next to the guide plate.

A modification to the test set-up was made by putting a 1 K ohm .002 mfd filter in the output of one amplifier in order to reduce noise. The scope was then synchronized on this channel. The single filter made it possible to increase the sweep rate of the oscilloscope, making it possible to measure with greater precision. When a recording was played back in the same direction as recorded, a slow skew drift of 120 microinches was observed. The static skew was measured to be 400 microinches.

It was noted that track 12 had 6 db dropouts for the full length of tape.

The head was then checked optically, and track #12 was found to have a scratch mark on the outer edge.

Observations with the microscope showed that the tape lifted off the guide surface .00012 inches in the forward direction and .00075 inches in the reverse direction on a final skew test with this set-up. The final skew and amplitude measurements are shown in Table 3.

The next test performed with the single-edge guidance set-up was with 3M951 lapped tape. An optical reading was taken to determine tape lift from the guide plate. In neither CW or CCW direction could any tape lift be observed, but it was observed that the edge of the tape image was shifting in the field of the microscope. Visual examination from the side showed that the guide edge of the tape was flipping slightly. This is an indication of excessive edge loading of the tape; therefore, the data does not represent a properly operating system. The resultant test data is shown in Table 4.

TABLE 3

Guidance System Test #1

C3 Single Edge

Speed: 10 ips

Tape: Memorex 62

Frequency: 10 KC / 10 K bps - 1 K bpi

Recording CW

CW - Playback - CCW

Amp. P - P	90 MV CH 1 80 MV CH 12	90 MV Ch 1 110 MV Ch. 12
Amp. Var.	80	110
Skew Max. + Min. + Min. - Max. -	22 μs slow drift (6 μs flutter)	20 μs flutter (0 drift)
Flutter P-P	6%	6%

Recording CCW

CW - Playback - CCW

Amp. P _ P	80 mv Ch 1 & 12	110 mv Ch. 1 100 mv Ch. 12
Amp. Var	80 mv	100 - 110 mv
Skew Max + Min. + Min. - Max. -	20 μs slow drift (6 μs flutter)	14 μs flutter (0 drift)
Flutter	4%	4%
Tape Lift	.00012	.00075

TABLE 4

Guidance System Test #2

C3 Single Edge

Speed: 10 ips

Tape: Lapped 3M951

Frequency: 10 KC / 10 K bps - 1 K bpi

Recording CW

CW - Playback - CCW

Amp. P-P	70 MV P-P Ch. 1 100 MV Ch. 12	Same @ 3000 bpi
Amp. Var.		
Skew Max. +	± 5 μs rapid drift	± 5 μs rapid drift
Min. +		
Min. -	Ch. 12 leads by 5 μs	Ch. 12 leads by 17 μs
Flutter	± 2% @ .010 inches from sync. point CCW ± 3% @ .010 inches from sync. point CW	

Recording CCW

CW - Playback - CCW

Amp. P-P	Ch. 1 70 MV CH. 12 40 MV	same 3000 bpi
Amp. Var.	20% 50%	same 3000 bpi
Skew Max +	± 5 μs rapid drift	± 5 μs rapid drift
Min. +	17 μs shift due to direction of playback	
Min -		
Max -	Ch. 12 leads by 5 μs	Ch. 12 leads Ch. 2 by 22 μs
Flutter	± 2% @ .010 inch	same

*Used for data reduction

Results and Conclusions - Single Edge Guidance

The test data reduction is as follows:	Static Skew = 85 microinches
	Dynamic Skew = 100 microinches P-P
	Skew Shift = 185 microinches
	Total Skew = 270 microinches
	Amplitude Modulation = 50%
Based on these results -	The single edge system does not meet the criteria for dynamic skew or amplitude modulation. In that the system did operate properly, it is felt that the inadequate results do not reflect the inherent capability of the system.

GROOVE GUIDANCE

Description - System A

The groove guidance system as shown in appendix 1 is based on the principle of a sapphire guide tracking in a groove which is embossed along the center line of the magnetic tape backing material. Thus, with this system the side-to-side motion of the tape is contingent on the straightness of the groove. The sapphire guide in this system does not rotate. Hence, the side to side motion, if the guide were rotating, is eliminated as a source of inducing dynamic skew. The two sapphire guide assemblies are located approximately two inches apart. On the opposite side of the tape (oxide side) two rollers are positioned approximately 2 1/4 inches apart. These rollers are used to guide tape onto the sapphire guides with a slight wrap angle so as to maintain tape to guide contact.

Groove Guidance Analysis

An initial analysis was made in order to determine the load carrying capacity of the groove embossed in the tape backing. At the time the analysis was made the anticipated design was not with a sapphire disc guide, but with a standard disc recording stylus. The maximum unit compressive load on the Mylar tape backing is given by:

$$S = 0.388\sqrt[3]{\frac{FE^2}{r^2}}$$

$$= 0.388\sqrt{7.5^2 \times 10^{10}}\ \sqrt[3]{F}$$

$$= .399 \times 10^6 \sqrt[3]{F} \text{ psi}$$

where:
- S = Unit stress, psi
- E = Modulus of elasticity, psi
- F = Load applied, lb.
- r = radius of stylus

Using the allowable pressure of 10^5 psi (LP records go to 1 to 2×10^6 psi)

$$F = \left(\frac{S}{.399 \times 10^6}\right)^3 = \left(\frac{10^5}{3.99 \times 10^5}\right)^3 = (.2506)^3 = .0157\# = 1 \text{ oz.}$$

The mass of tape to be guided at each post is:

$$m = \frac{w}{g} = \frac{2.5 \times 4.22 \times 10^{-5}}{g} = \frac{10.55 \times 10^{-5} \text{ lb.}}{g}$$

where: m = mass

g = 32.2 ft/sec.

w = weight, lb.

a = acceleration ft/sec/sec

Then, the shock capacity is:

$$\frac{a}{g} = \frac{F}{w} = \frac{.0157\sqrt{212}}{10.55 \times 10^{-5}} \cong 105 \text{ g's per stylus}$$

The derived 105 g value indicates the maximum shock load that this guiding system can sustain without distorting the groove.

In evaluating a disc guide with an edge profile matching the shape of a regular stylus, it was felt that it would have a higher shock loading capacity, as well as an advantage in guiding, because it would have an improved lead in for centering the groove and a longer flank length around the disc which would smooth out any surface roughness in the cut guidance groove.

In addition, small deviations from a straight line in the groove would be averaged out over the longer contact surface of the sapphire disc guide.

Grooving Tape

Experiments in both grooving and embossing tape were made to determine the feasibility of each. The grooving technique involves the actual removal of material (Mylar) from the tape backing by means of a scraping action. The embossing technique involves the displacement of material from one area to another.

Initial experiments were carried out in grooving the backing of 1 mil Mylar tape. These experiments consisted of mounting a short length of tape to a mandrel which was turned down in a lathe to within .00015 TIR. A sapphire microgroove cutting needle (a standard record cutting stylus) was mounted in the tool holder and fed into the tape backing until a groove was cut. This same method was used with heat applied to the needle. Microscopic inspection showed that a more uniform groove is produced using the hot needle method. Based on these results, further work with hot cutting stylii and embossing stylii was done using a commercial heating unit. This resulted in satisfactory grooves with the heated sapphire cutting stylus. However, the stylus became dull and the cut degraded after about ten or twelve feet of cut.

The tests on embossing tape with the hot embossing stylus were very successful on 3M951 tape. After an initial set-up period, about 130 feet of groove were formed with no sign of degradation of the groove or wear on the stylus. After forming about 70 feet of groove in 3M951 tape, a length of Memorex tape was tried. There was a distinct chatter mark in the bottom of the groove. The stylus did not appear to be worn or damaged and more

3M951 tape was grooved. This tape was then used to perform the skew test on the groove guidance system.

The technique for embossing the groove is as follows:

First the web is guided past the forming tool in a reproducible manner. This is done by means of three crowned rollers in the web path. The web may be spliced into an endless loop or be run in a constant tension reeling system. The web is then run through a sufficient number of cycles so that its position becomes stabilized. The groove is then formed in the desired lateral position.

The crowned roller at the forming station has a very shallow hat section profile. The top of the hat is between one-half and two-thirds of the width of the web. The sides of the hat are made with an angle of 2^{o} to 3^{o} and the brims are made equal in diameter. The groove is actually formed by means of a standard phonograph sapphire hot embossing stylus. The holder for the stylus is in the form of a three tined fork with the center tine shorter and raised above the level of the outer tines. The stylus is mounted in the center tine with the depth set so that the tip of the stylus touches the top of the hat when the outer tines rest on the brim of the hat section. The root thickness beneath the groove is then adjusted by offsetting the stylus and holder in the tangential direction. The lateral location of the groove is adjusted by axial movement of the stylus. The stylus holder should be offset in the direction so that the tip drags on the material rather than digs in, as shown in Figure 5.

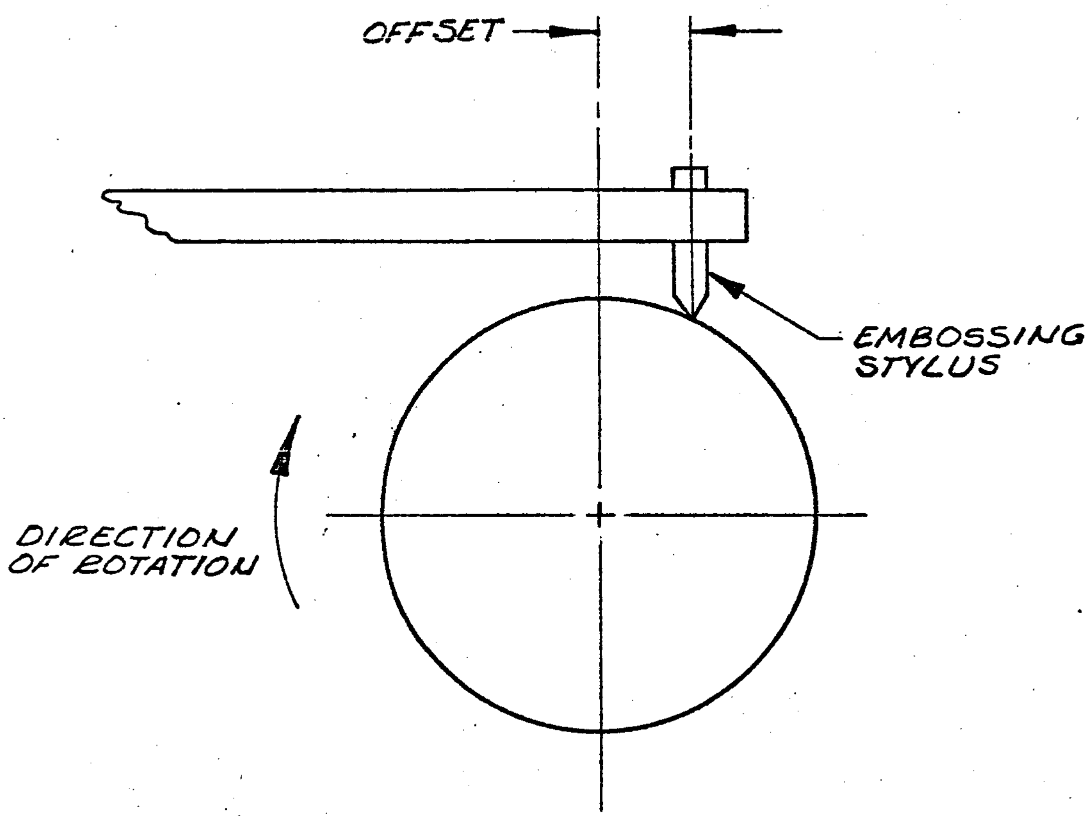


FIGURE 5
EMBOSSING STYLUS POSITION

Testing - Groove Guidance

Pre-grooved tape was installed into the unit. On the first attempt, the tape would not track on the sapphire guides. Ungrooved tape was then installed with a backup plate pressing against the oxide tape surface at the guide. (See Figure 6). The sapphire guides were then rotated in order to emboss a groove in the tape, but this resulted in a multitude of grooves, instead of a single groove. Another attempt was made with the pre-grooved tape. This time with backup plates and protruding the sapphire discs. The sapphire discs protruded .005 to .010 inches beyond the guide posts. This test resulted in a complete loss of signal upon playback.

Further attempts at grooving Mylar were made. First, a strip of 3-mil Mylar was cut approximately 1-3/8" wide and trimmed to run true on the grooving set-up. A center groove was embossed, using a hot stylus, and then two stylii were positioned to trim the edges to the 1/2" width. This length of Mylar was then installed into the breadboard transport, without backup plates. This test was not successful because the tape would not track on the guides, but it did track properly within the groove, using backup plates as shown in Figure 7. This same procedure was then repeated, using 3 mil x 35 mm tape which was trimmed and embossed. The resultant data for this test is shown in Table 5.

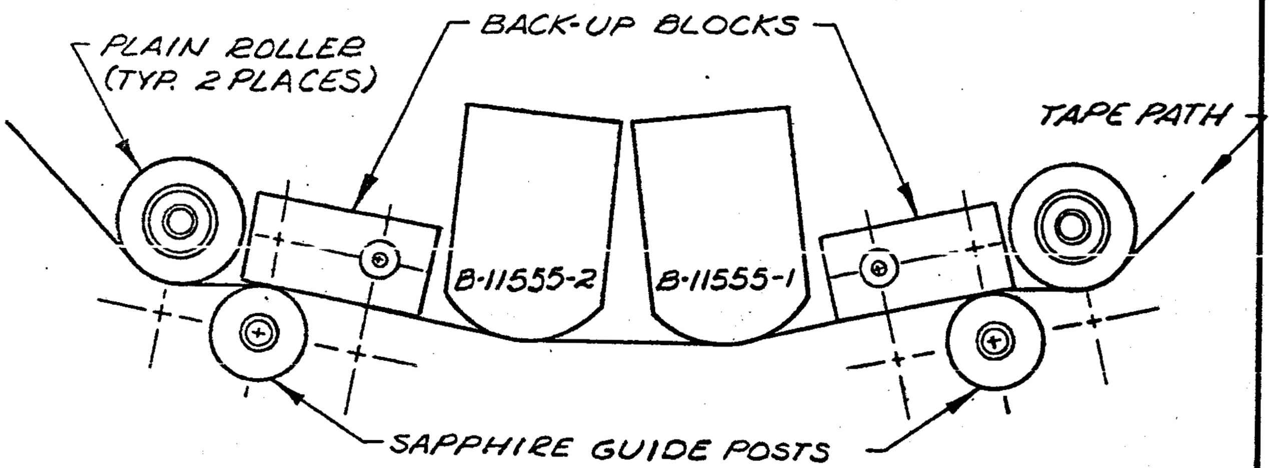


FIGURE 6
GROOVE GUIDANCE SYSTEM A
WITH BACK-UP PLATE

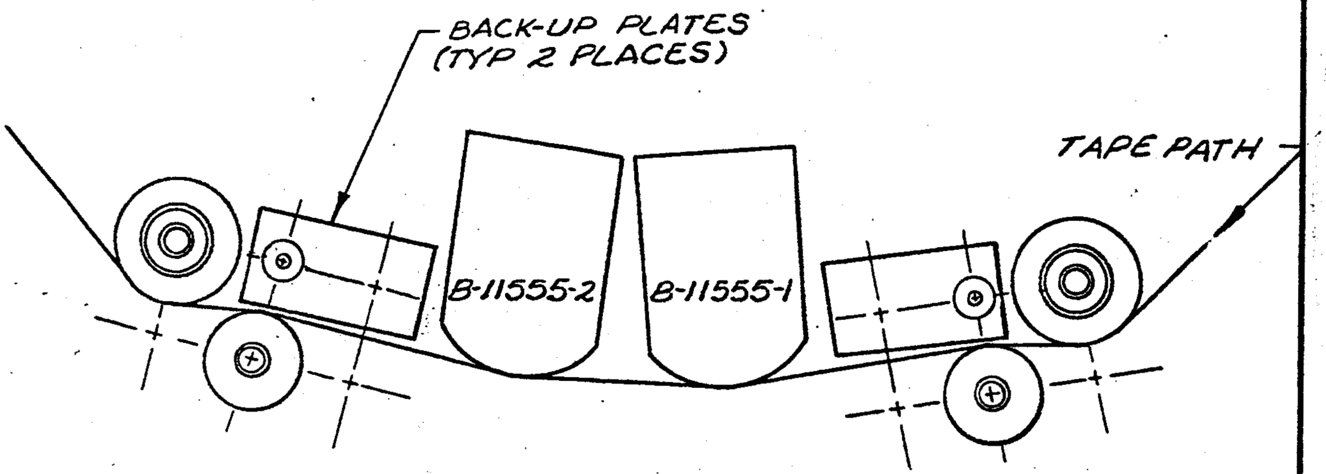


FIGURE 7
GROOVE GUIDANCE SYSTEM A
WITH BACK-UP PLATE

TABLE 5

Guidance System Test

System A - Groove Guidance

Speed 10 ips

Tape 3 M 8941

Frequency 500 cycle / Density - 100 bpi

Recording CW

CW - Playback - CCW *

	CW	CCW *
Amp. P-P	Ch. 1-.8V - Ch. 12 -1.2V	Ch. 1 -.6V - Ch. 12 1.1 V.
Amp. Min.	Ch. 1-.4V - Ch. 12 - .8V	Ch. 1 - .4V - Ch. 12 .8 V.
Skew. Max. +	20 μs Ch. 1 leading	30 μs Ch. 1 leading
Min. +	10 μs Ch. 1 leading	20 μs Ch. 1 leading
Min. -		
Max. -		
Flutter		

Recording CCW*

CW - Playback - CCW

	CW	CCW
Amp. P-P	Ch. 1 - 8V Ch. 12 - 1.1V	Ch. 1 - .9V - Ch. 12 1.1V
Amp. Min.	Ch. 1 - 4V Ch. 12 - .8V	Ch. 1 - .5V - Ch. 12 .8V
Skew Max. +	30 μs Ch. 1 leading	20 μs Ch. 1 leading
Min. +	20 μs Ch. 1 leading	10 μs Ch. 1 leading
Min. -		
Max. -		
Flutter		

*Used for data reduction

Results and Conclusions - Groove Guidance

The test data reductions are as follows:	Average Static Skew = 50 microinches
	Dynamic Skew = 100 microinches P-P
	Skew Shift = 200 microinches
	Total Skew = 500 microinches
	Amplitude modulation = 50%
Based on these results -	The groove guidance system does not meet the criteria for either dynamic skew or amplitude modulation.

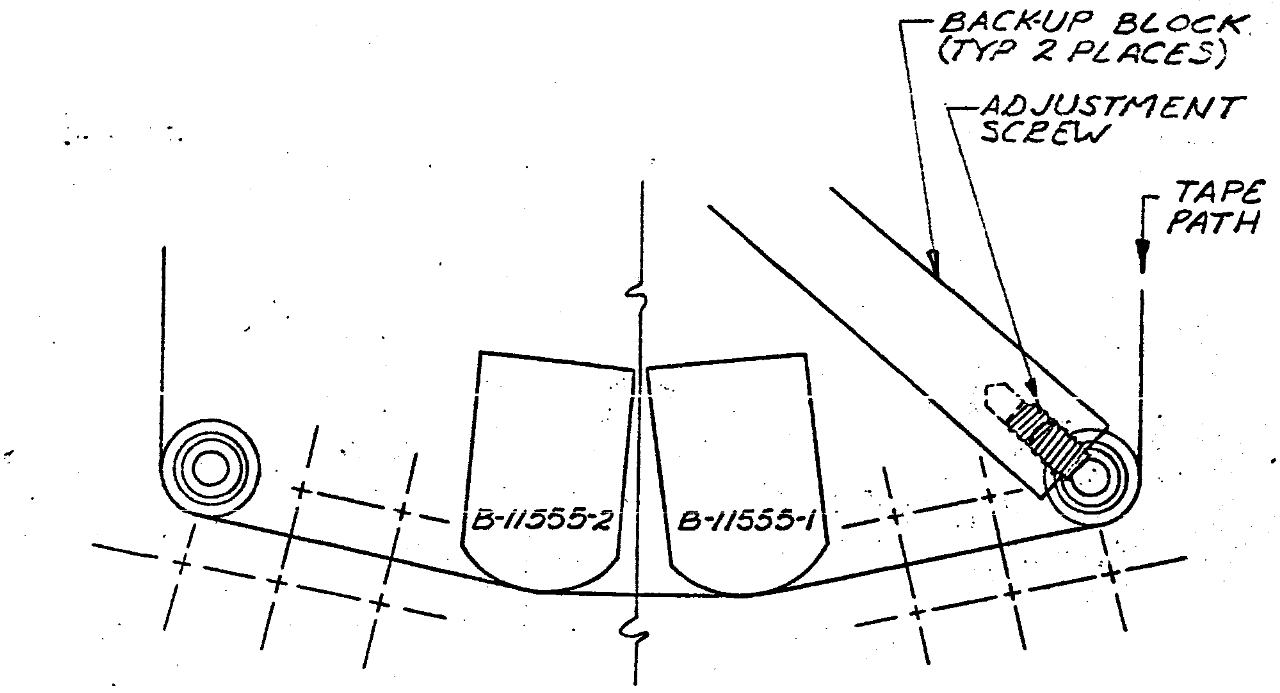


FIGURE 8
INTERNAL GUIDANCE SYSTEM E
WITH ADJUSTMENT SCREW

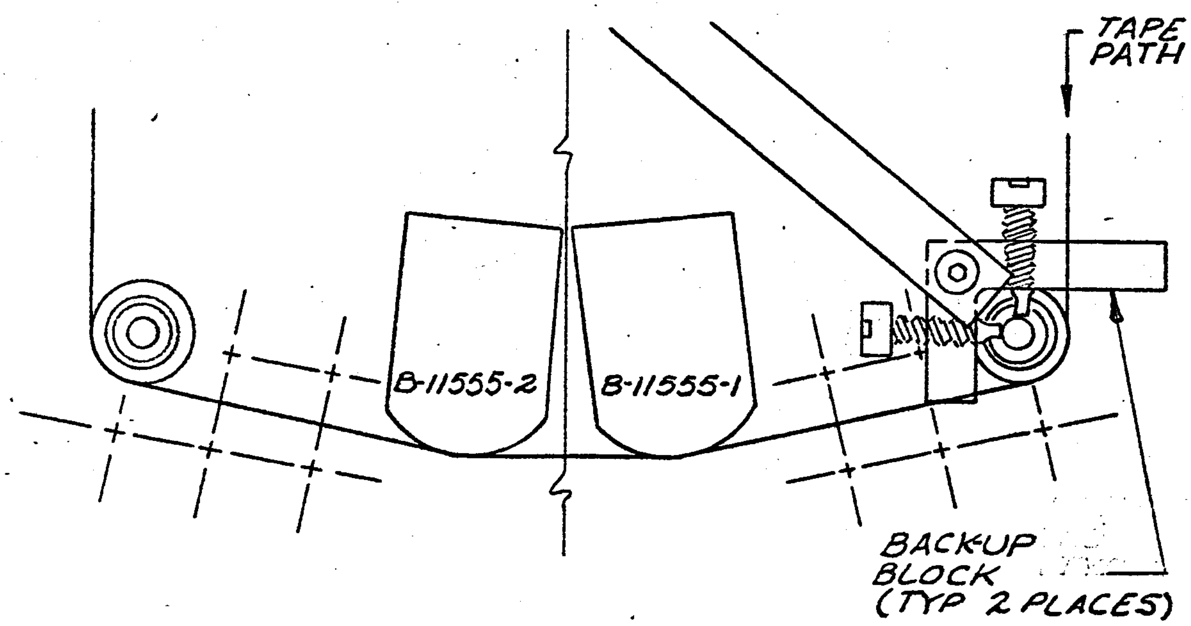


FIGURE 9
INTERNAL GUIDANCE SYSTEM E
WITH BACKUP BLOCK

INTERNAL GUIDANCE

Description - System E

The internal guidance system is comprised of two crowned rollers which are located on either side of the head assembly. The spacing of these rollers is approximately 2-1/4 inches (See appendix 9). With a crowned roller guiding system the transverse motion is minimized because the tape tends to travel toward the high diameter of the roller. For this to happen a non-slip condition must be maintained between the tape and the roller. Rollers can be crowned with a radius, tapers meeting at an apex or as in this system, tapers with a flat crown. The tapers with a flat crown have the advantage of providing equal or better centering action with less of an induced stress in the tape. (E. J. Renner, Belt Pulley Crown, Machine Design, 1960).

Testing - Internal Guidance

The first test run in this system indicated that the tape was slowly creeping up, and finally off, the lower track. It was then determined that the crowned rollers were leaning in toward the heads due to tape tension. To correct this, backup blocks were made with an adjustable screw so that the rollers could be adjusted into perpendicularity under tape tension. (See Figure 8). This did not prove satisfactory. New backup blocks were then installed as shown in Figure 9. After several adjustments were made to balance the skew measurements in both directions, the tests were completed using the play-back head as a record head in order to eliminate static skew. In this last test the head was driven directly with a 500 cycle signal from a square wave generator. The resulting data is shown in Table 6. It will be noted that a 2 - 4 microsecond time delay was detected between the two playback amplifiers. This was determined by interchanging the two channels which were measured.

Results and Conclusions - Internal Guidance

The test data reduction is as follows:

Average static skew = 5 microinches

Dynamic skew = 40 microinches P-P

Skew shift = 25 microinches

Total skew = 80 microinches

Amplitude Modulation ≈ 0%

Based on these results - The internal guidance system meets the criteria for both dynamic skew and amplitude modulation.

TABLE 6
Guidance System Test

System E - Internal Guidance

Speed 10 ips

Tape 3M 951

Frequency 500 cyc. / Density - 100 bpi

Recording CW
CW - Playback - CCW*

	CW	CCW*
Amp. P-P	1V	1 V
Amp. Var	0V	0 V
Skew Max. +	0 μs	4 μs Ch. 1 leading
Changed Amp. Min. +	1 μs Ch. 1 leading	2 μs Ch. 1 leading
Min. -		
Max. -	Skew ± 2 μs	
Flutter	2%	2%

Recording CCW
CW - Playback - CCW

	CW	CCW
Amp. P-P	1V	1 V
Amp. Var.	0V	0 V
Skew Max. +	3 μs Ch. 1 leading	0 μs
Changed Amp. Min. +	2 μs Ch. 1 leading	3 μs Ch. 1 leading
Min. -		
Max. -	Skew ± 2 μs	
Flutter	2%	2%

*used for data reduction

FLANGE GUIDANCE

Description - System C2

The flange guidance system consists of a head assembly with a flanged roller positioned on either side of the assembly. (See Figure 10). The guide rollers are spaced approximately 2-1/4 inches apart. The guiding flanges in these roller assemblies are in a fixed position and do not rotate. The flanges are spaced to a minimum clearance to the tape, so as to limit transverse tape motion. Unlike the trough guiding system, continuous guiding surfaces do not exist from one roller to the other.

Testing - Flange Guidance

Upon installing and running a sample of 3M951-3 tape in test set-up (See Figure 10), it was noted that the tape was not tracking properly. This was due to improper clearance in the guides.

Reeves Soundcraft tape (5BTM36-1. 0-#3) was then loaded into the system. The guides were adjusted with shims for a guide dimension of .4993 inches, which constitutes .0018 inch allowance over the mean width of this tape. The resultant data is shown in Table 7. Further adjustments in roller perpendicularity and guide clearance were made with respect to 3M951 tape. The screw adjustments were made until tape was tracking in the assembly properly. This technique resulted in improved skew measurements. (See Table 8). The guide to tape allowance for this test was set at .0008 inches.

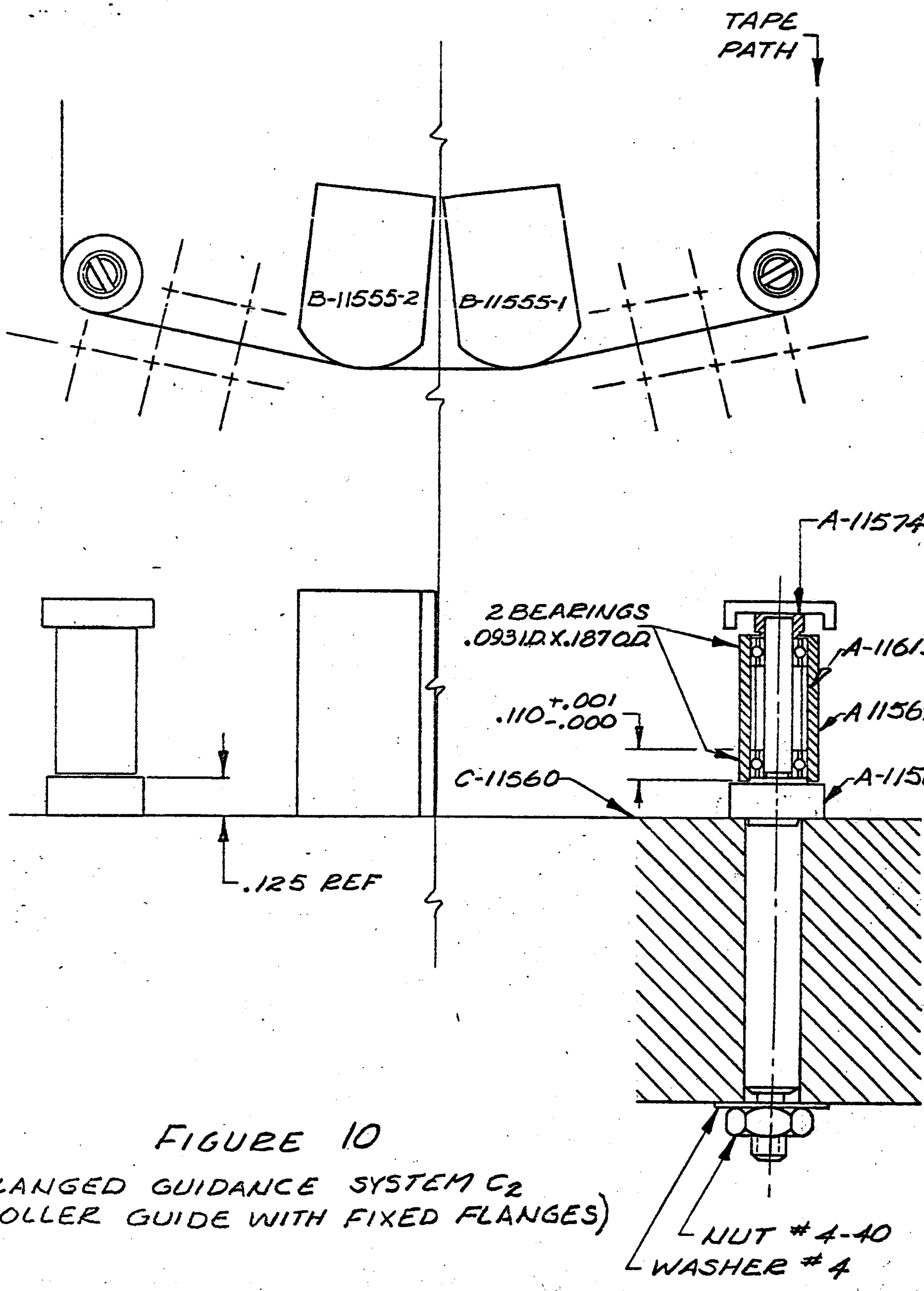


FIGURE 10

FLANGED GUIDANCE SYSTEM C_2
(ROLLER GUIDE WITH FIXED FLANGES)

Results and Conclusions - Flange Guidance

The test data reduction is as follows:	Average Static Skew = 0 microinches
	Dynamic Skew = 20 microinches P-P
	Skew Shift = 90 microinches
	Total Skew = 200 microinches
	Amplitude Modulation = 5%
Based on these results -	The flange guidance system meets the criteria for both dynamic skew and amplitude modulation.

TABLE 7

Guidance System Test

C 2 - Flange Guidance

Speed 10 ips

Tape Soundcraft 58 TM36 - 1, 0-#3

Frequency: 500 cyc / Density - 100 bpi

Recording CW

CW - Playback - CCW

	CW	CCW
Amp. P-P	1.6V Ch 1 1 V Ch. 2	1.6 V Ch. 1 .8 V. Ch. 2
Amp. Var.	± .05 V Ch. 1; ± .1 V. Ch. 2	± .05 V. Cha. 1 ± .1 V Ch. 2
Skew Max. +	15 μs Ch. 1 leading	12 μs Ch. 1 leading
Min. +	10 μs Ch. 1 leading	8 μs Ch. 1 leading
Min. -		
Max. -		
Flutter		

Recording CW

CW - Playback - CCW

	CW	CCW
Amp. P-P	1.5 V Ch. 1 1V Ch. 2	1.6 V. Ch. 1 1.5 V. Ch. 2
Amp. Var.	± .05 V Ch. 1 ± .1 V. Ch. 2	± .05V Ch. 1 and 2
Skew Max. +	15 μs Ch. 1 leading	12 μs Ch. 1 leading
Min. +	10 μs Ch. 1 leading	8 μs Ch. 1 leading
Min. -		
Max. -		
Flutter		

TABLE 8

Guidance System Test

System C 2 - after visual adjustment of Roller "B"

Speed 10 ips

Tape 3M 391

Frequency 500 cyc   Density - 100 bpi

Recording CW
CW - Playback - CCW

	CW	CCW
Amp. P-P	1.2 V Ch. 1 and 2	1.1 V. Ch. 1 and 2
Amp. Var	± .025 V Ch. 1 & 2	± .025 V Ch. 1 and 2
Skew Max. +	8 μs Ch. 1 leading	10 μs Ch. 1 leading
Min. +	6 μs Ch. 1 leading	8 μs Ch. 1 leading
Min. -		
Max. -		
Flutter	1%	1%

Recording CCW *
CW - Playback - CCW *

	CW	CCW
Amp. P-P	1.1 V. Ch. 1 and 2	1.2 V. Ch. 1 and 2
Amp. Var.	± .025 V Ch. 1 & 2	± .025 Ch. 1 and 2
Skew Max. +	10 μs Ch. 1 leading	10 μs Ch. 1 leading
Min. +	8 μs Ch. 1 leading	8 μs Ch. 1 leading
Min. -		
Max. -		
Flutter	1%	1%

*used for data reduction

TROUGH GUIDANCE

Description - System D-2

The trough guidance system consists of two rollers on either side of the head assembly spaced approximately 2-1/4 inches apart. Between the two rollers are two continuous guide plates, one guiding the bottom edge of the tape and one the top edge. These two plates are spaced apart by standoff spacers which are sized to maintain a minimum clearance between the guide surfaces and the tape edges. (See Figure 11). This system differs from the flange guidance system in that tape is guided throughout the head assembly area.

Testing - Trough Guidance

3M951 tape was installed into system D 2 as shown in Figure 11 and the tension was stabilized. Tests were made with respect to amplitude and skew with the resultant data shown in Table 9. It was noted that during this test as the tape left the reel hubs, it had a tendency to ride high as it entered the trough. However, as it left the trough, it was tracking at the proper level. This was true for both CW and CCW motion. It was also observed that the maximum and minimum value of the dynamic skew changed slowly throughout the tape pass.

Results and Conclusions

The test data reduction is as follows:

Average Static Skew = 20 microinches
Dynamic Skew = 20 microinches P-P
Skew Shift = 120 microinches
Total Skew = 280 microinches
Amplitude Modulation = 5%

Based on these results - The trough guidance system meets the criteria for both dynamic skew and amplitude modulation.

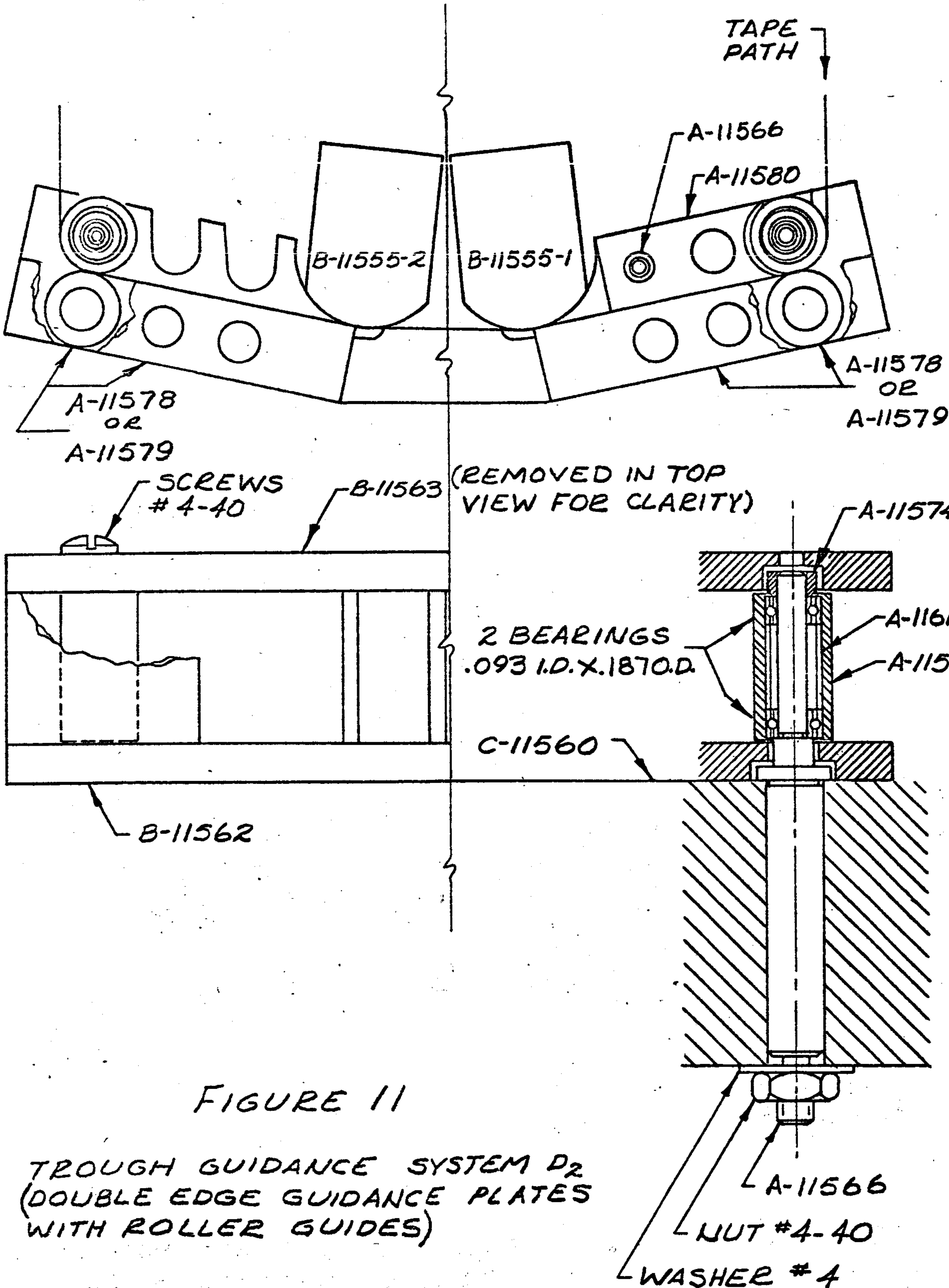


FIGURE 11

TROUGH GUIDANCE SYSTEM D_2
(DOUBLE EDGE GUIDANCE PLATES WITH ROLLER GUIDES)

TABLE 9

Guidance System Test #1

D_2 - Trough Guidance

Speed 10 ips

Tape 3M951

Frequency 500 cyc. / Density - 100 bpi

Recording CW *
CW - Playback-CCW

	CW	CCW
Amp. P-P	1. 3 V Ch. 1 and 2	1. 2 V. Ch. 1 and 2
Amp. Var.	± .025 V. Ch. 1&2	± .025 V. Ch. 1 and 2
Skew Max. +	12 μs Ch. 1 leading	16 μs Ch. 1 leading
Min. +	10 μs Ch. 1 leading	14 μs Ch. 1 leading
Min. -		
Max. -		
Flutter	1%	1%

Recording CCW
CW - Playback- CCW

	CW	CCW
Amp. P-P	1. 3V. Ch. 1 and 2	1. 3V. Ch. 1 and 2
Amp. Var.	± .025 V. Ch. 1&2	± .025V. Ch. 1 and 2
Skew Max. +	16 μs Ch. 1 leading	10 μs Ch. 1 leading
Min. +	14 μs Ch. 1 leading	8 μs Ch. 1 leading
Min. -		
Max. -		
Flutter	1%	1%

*Used for data reduction.

SPROCKET GUIDANCE

Description and Evaluation - System B

The sprocket guidance system consists of two sprocketed rollers placed on either side of the head assembly. The tape which passes over these sprockets has perforated sprocket holes positioned along the center line of the tape. The sprocket rollers in this system are idlers and serve only to keep the tape from moving from side to side (transverse motion). In this system both tooth-to-tooth alignment as well as hole-to-hole alignment on the tape are variables which add to the effectiveness of limiting transverse motion of the tape.

The sprocket guidance system was abandoned early in the program due to the difficulty of obtaining hardware. Various sources were contacted which could possibly fabricate the sprockets and punch sprocket holes in the tape to the required tolerances. The main problem in perforating holes in tape is maintaining hole-to-hole tolerance in the lateral plane when using the edge of the tape as a reference. This would require a punch and die set which would have to index tape in a guide as precisely as any of the edge guiding systems. As for the sprocket tolerances, it was indicated that lateral runout tolerance could be held, but hand lapping would very likely be required. Thus, the difficulty of this system is that there are two moving elements (sprocket and punched holes in the tape) requiring tolerances twice as tight as systems having one stationary element. (see appendix 2 for original design). Since satisfactory hardware could not be obtained within the economic limits of the program, further work was abandoned.

SUMMARY CONCLUSIONS

1. Five different tape guidance systems were tested for dynamic skew, static skew and amplitude modulation. Based on a packing density of 10^4 bits per lineal inch, Non-return To Zero (NRZ) recording technique on parallel tracks of 6 mils in width, the goal of 50 micro-inches peak-to-peak dynamic skew for .25 inch width of tape, and a maximum of 10% amplitude modulation, three of the systems tested met these criteria. They are: (1) internal guidance - System E (2) flange guidance - System C 2, and (3) trough guidance, System D 2. The other systems tested did not meet either criteria - i.e., (4) single edge guidance - System C3, and (5) groove guidance, System A.

2. Although three systems met the criteria of dynamic skew and amplitude modulation, the phenomenon of skew shift and average static skew was observed. If a recorder system were required to reproduce recorded data in both forward and reverse directions of tape travel, these two parameters would be considered dynamic and would have to be compensated for in order to achieve pulse synchronization. If data is to be reproduced in one direction of tape travel only, these displacements are systematic and could be compensated for by electronic means.

3. Behavior of each system was not tested under possible extreme environmental conditions. In order to establish the true merits of the acceptable systems, it is recommended that effort should be expended in this area.

4. The reliability of each of the acceptable systems has not been ascertained. In order to gain further knowledge of the comparative merits of each system, an endurance testing program is recommended.

5. A statistical evaluation of tapes shows that there is no significant difference between brands of commercially slit tape as far as width variability is concerned. However, there is a significant difference between slit tape and lapped tape. The variability of lapped tape is predicted to be one-half that of slit tape.

6. The only test performed with lapped tape was in the single-edge guidance system. This test was unsuccessful because of tape edge buckling. It is felt that if lapped tape were tested in the flange and trough guidance systems, further improvements in dynamic skew and amplitude modulation could be obtained.

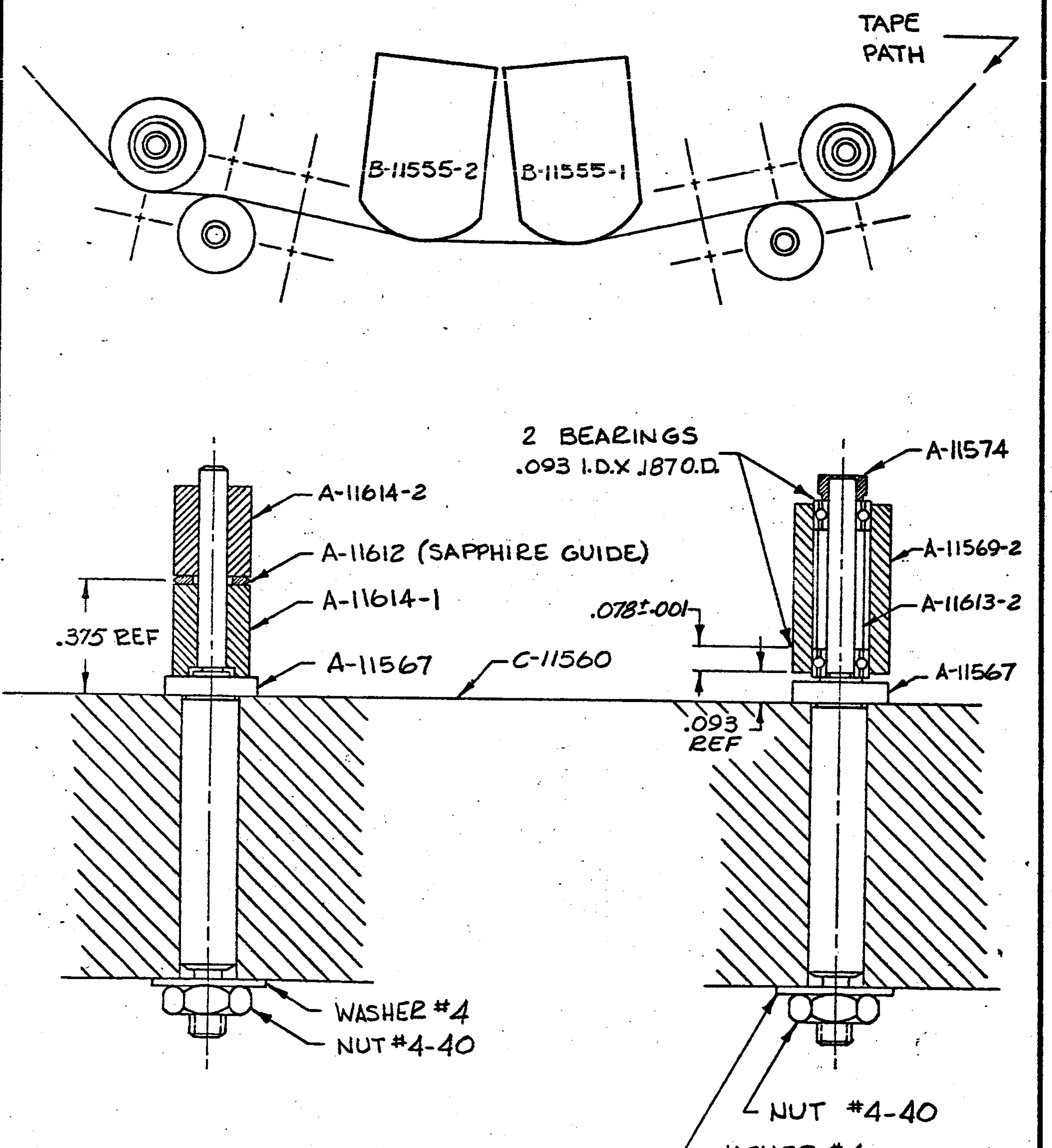
7. A simple tape width gauge was developed which can measure the width of tape at any point with a sensitivity of 25 microinches and a precision of better than 50 microinches. It is felt that this apparatus can attain wide use in evaluating tape width, and with proper modification of the apparatus it would be useful in obtaining tape edge straightness measurements heretofore not available.

8. The important test results are as follows:

Guidance System		Dynamic Skew Microinch P-P	Amplitude Modulation %
Single Edge	(C 3)	100	50
Groove	(A)	100	50
Internal	(E)	40	0
Flange	(C 2)	20	5
Trough	(D 2)	20	5

9. One unplanned result of this study was some quantitative data on the tolerances which will be required in high density recorders. In the analysis of the single edge guidance system it was shown that a uniform taper amounting to 0.0003 inches over a half inch wide roller should be sufficient to bias the tape completely to one side. In the testing of this system it was found that a deflection of 0.00015 inches (caused by the tape tension) was sufficient to over balance this biasing effect. In other tests it was found that a change in perpendicularity of 0.0001 inches could significantly affect the guidance and skew. This demonstrates that very high density recorders will require tolerances which are at the limit of present day precision fabricating methods. Further, the physical design of these mechanisms will have to incorporate design details which minimize elastic deflections and alignment errors.

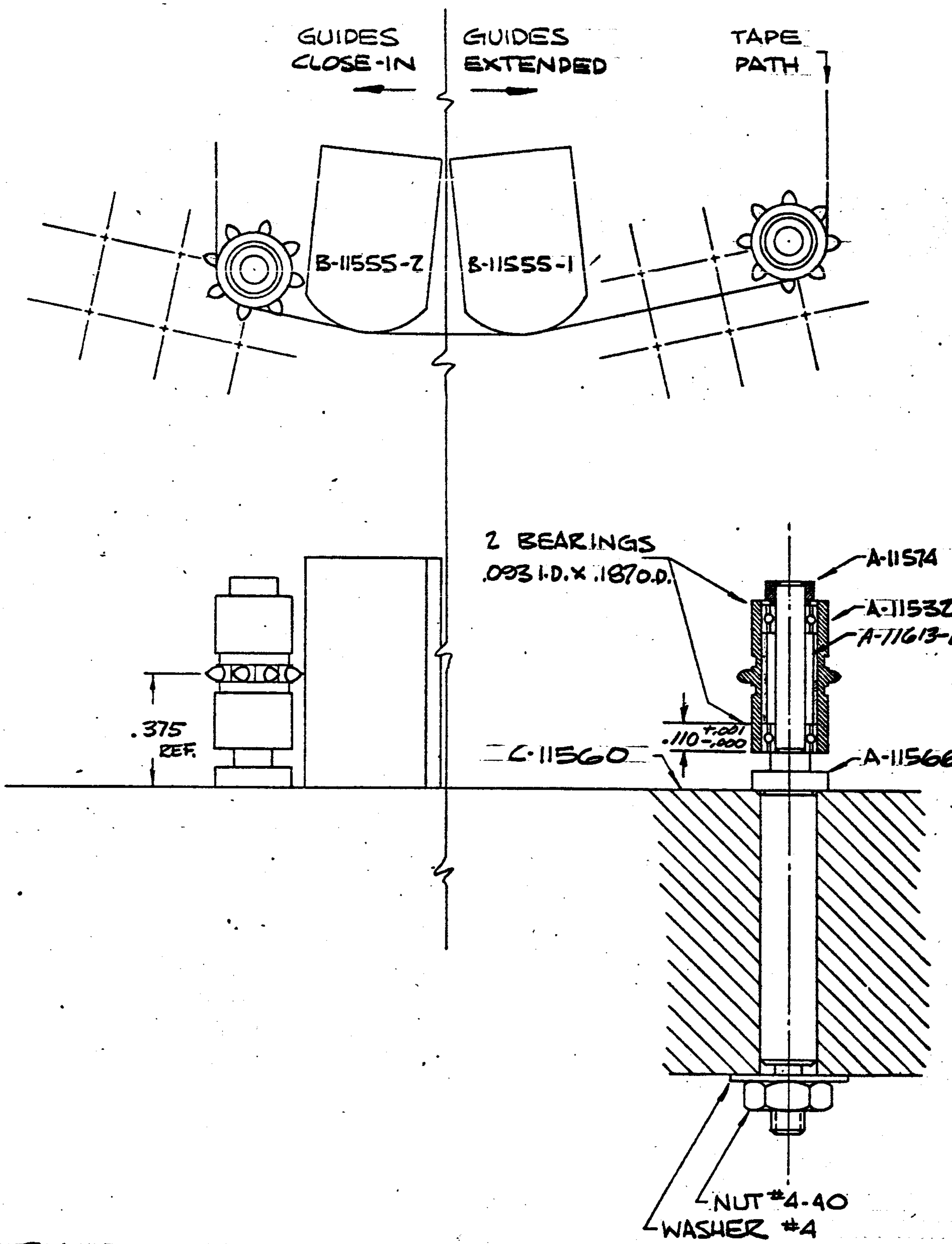
APPENDIX I



SYSTEM A-GROOVE GUIDANCE

A-11611-1

APPENDIX 2

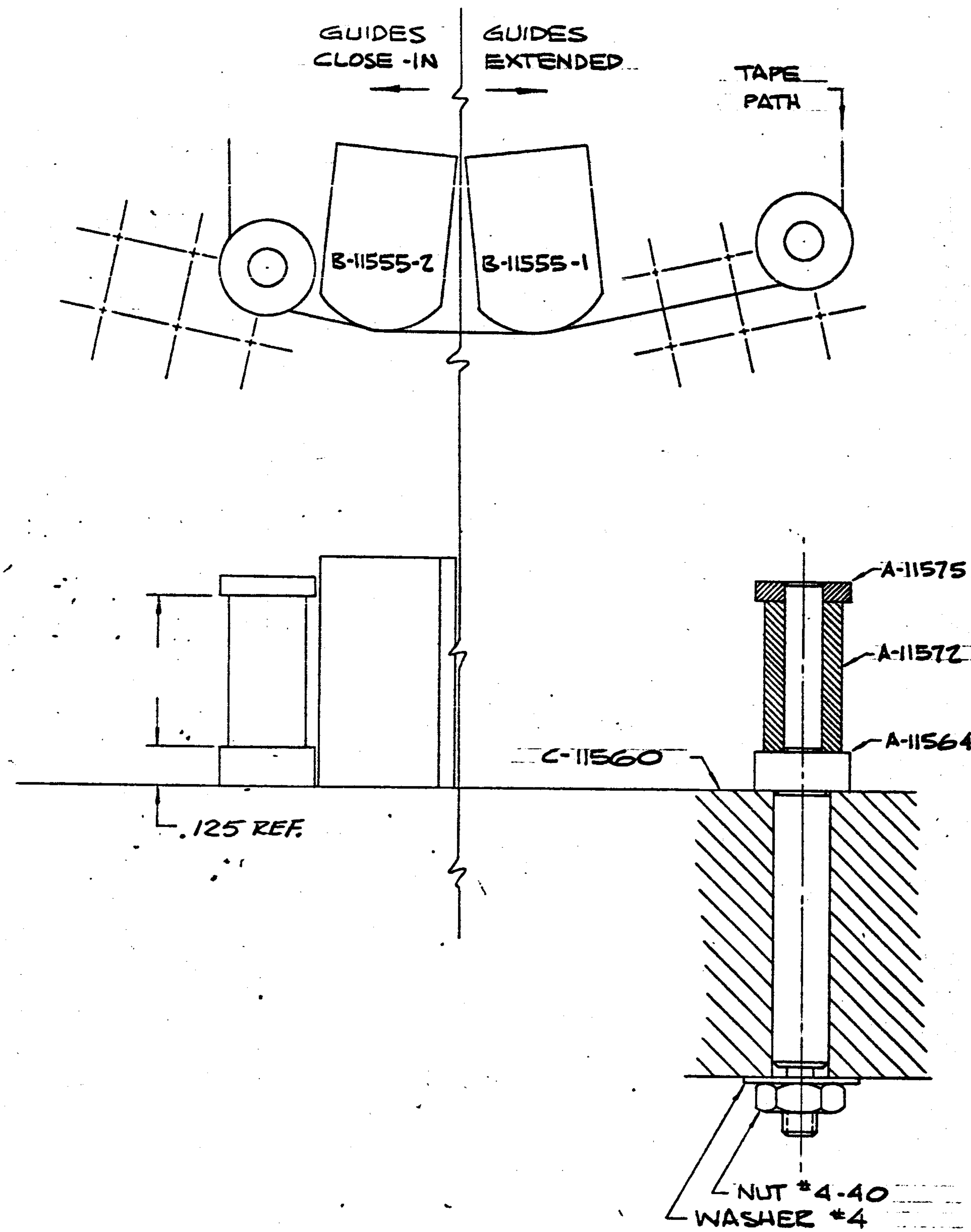


SYSTEM B - SPROCKET GUIDANCE

A-11611-2

3·30·64 R.S.K.

APPENDIX 3



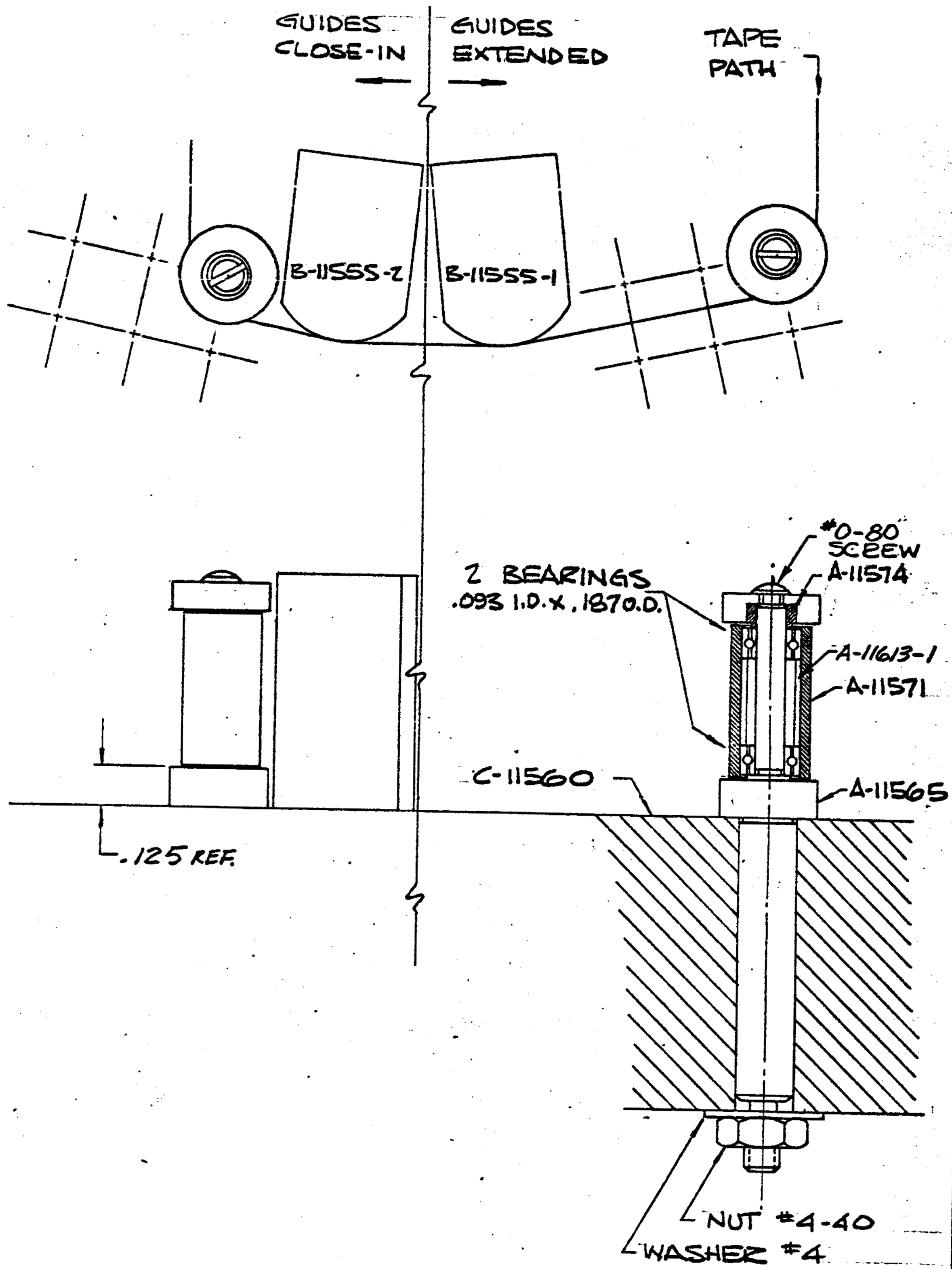
SYSTEM C_1 - FLANGED GUIDANCE
(FIXED GUIDES WITH FIXED FLANGES)

A-11611-3

33064 R.S.K.

KINELOGIC CORPORATION
29 SO. PASADENA AVE., PASADENA, CALIFORNIA

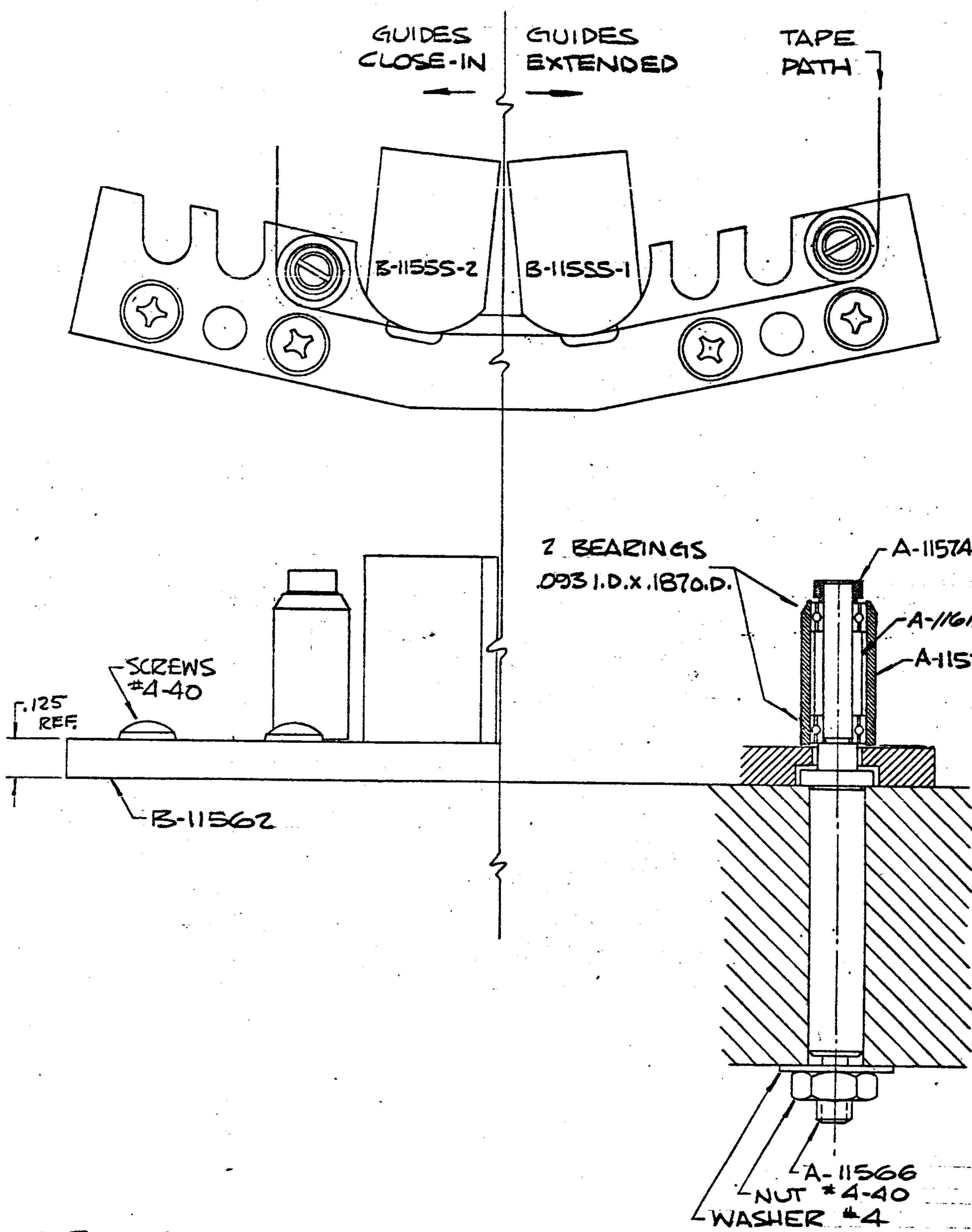
APPENDIX 4



SYSTEM C_2 – FLANGED GUIDANCE
(ROLLER GUIDE WITH FIXED FLANGE)

A-11611-4
3·30·64 R·S·K·

APPENDIX 5



SYSTEM C3 - SINGLE EDGE GUIDANCE
(BIASED ROLLER WITH
SINGLE EDGE GUIDANCE PLATE)

A-11611-5

3.30.64 R.S.K.

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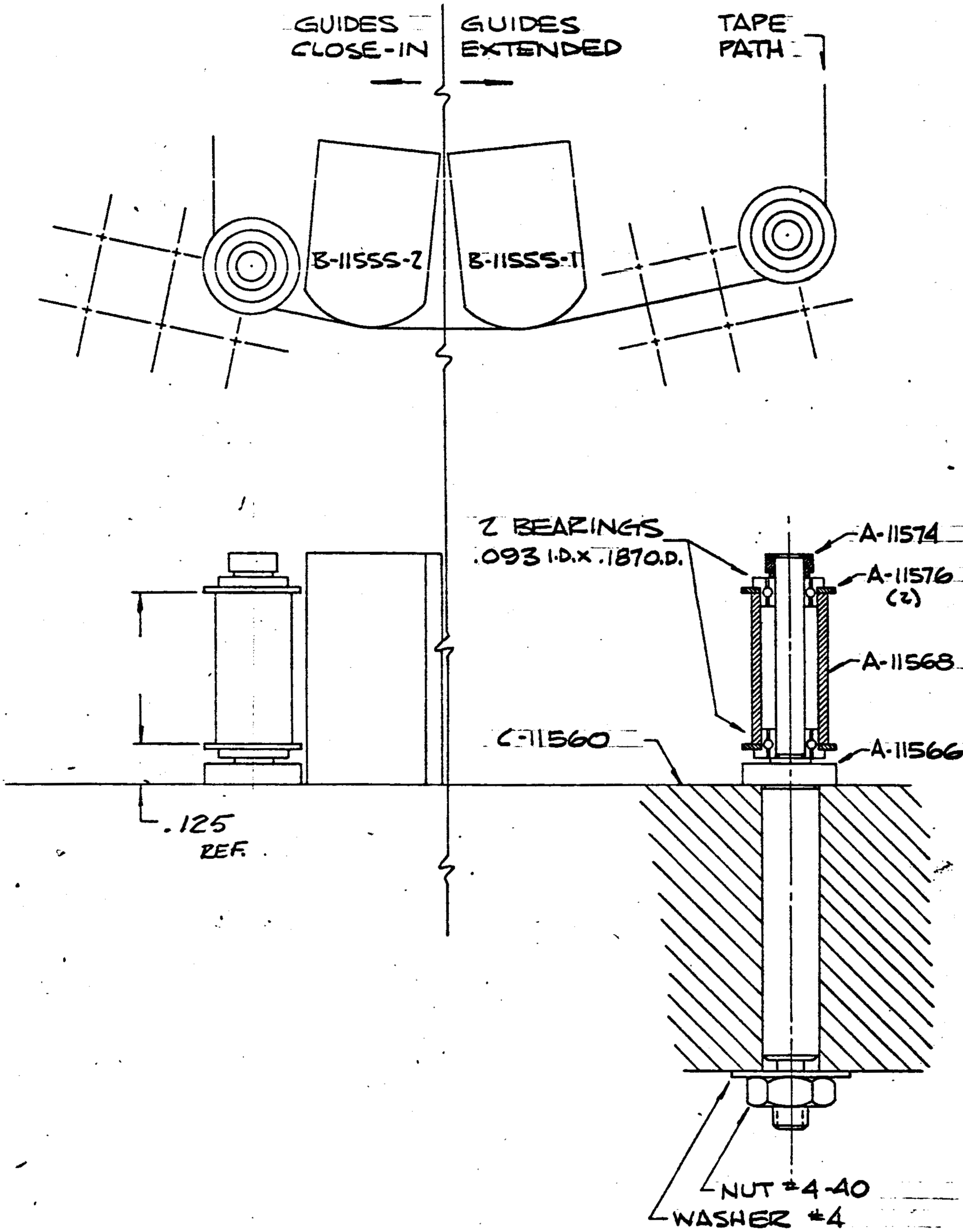
29 SO. PASADENA AVE., PASADENA, CALIFORNIA

APPENDIX 6

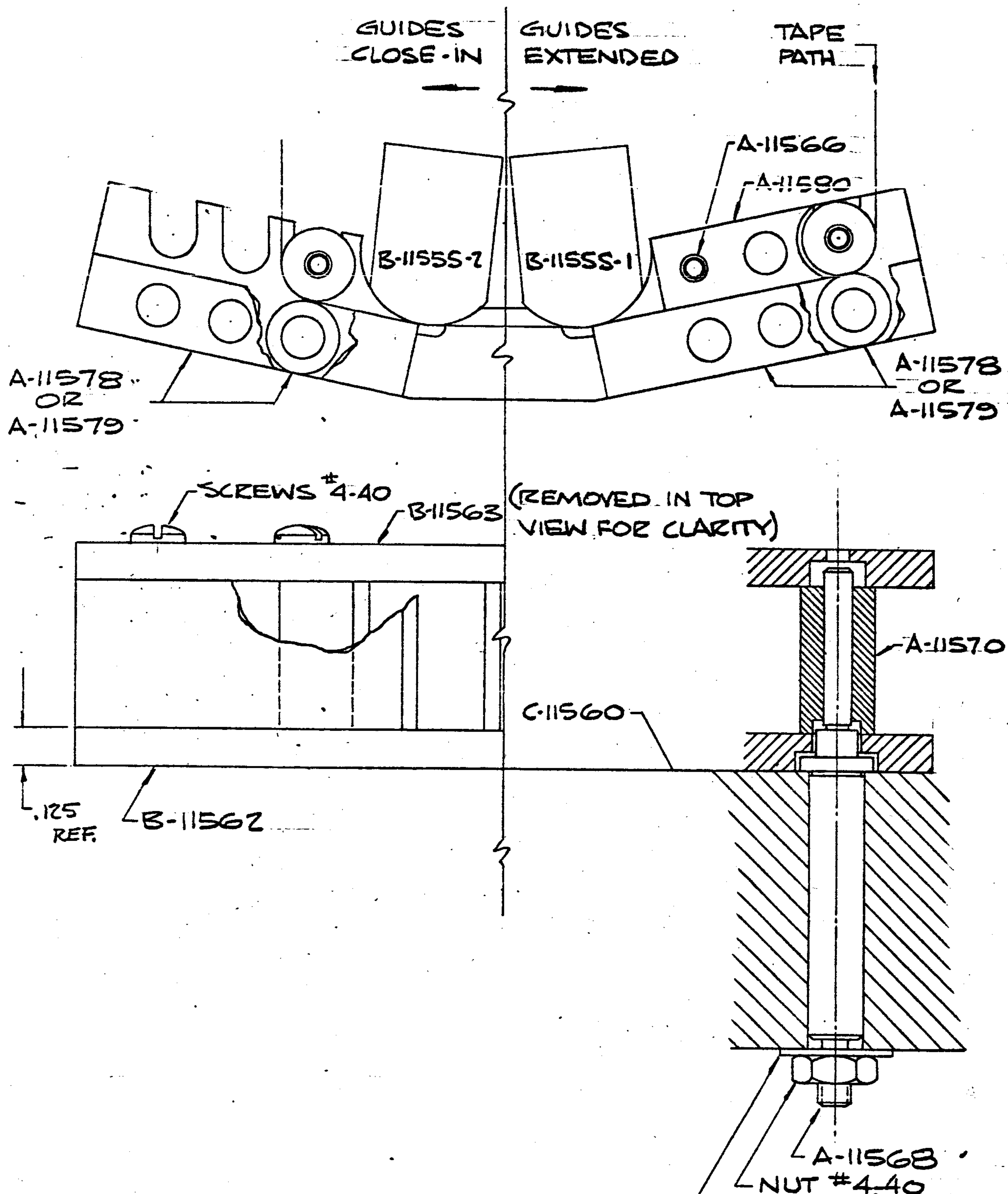


SYSTEM C_4 - FLANGED GUIDANCE
(ROLLER GUIDES WITH ROLLER FLANGES)

A-11611-6

3·30·64· R·S·K·

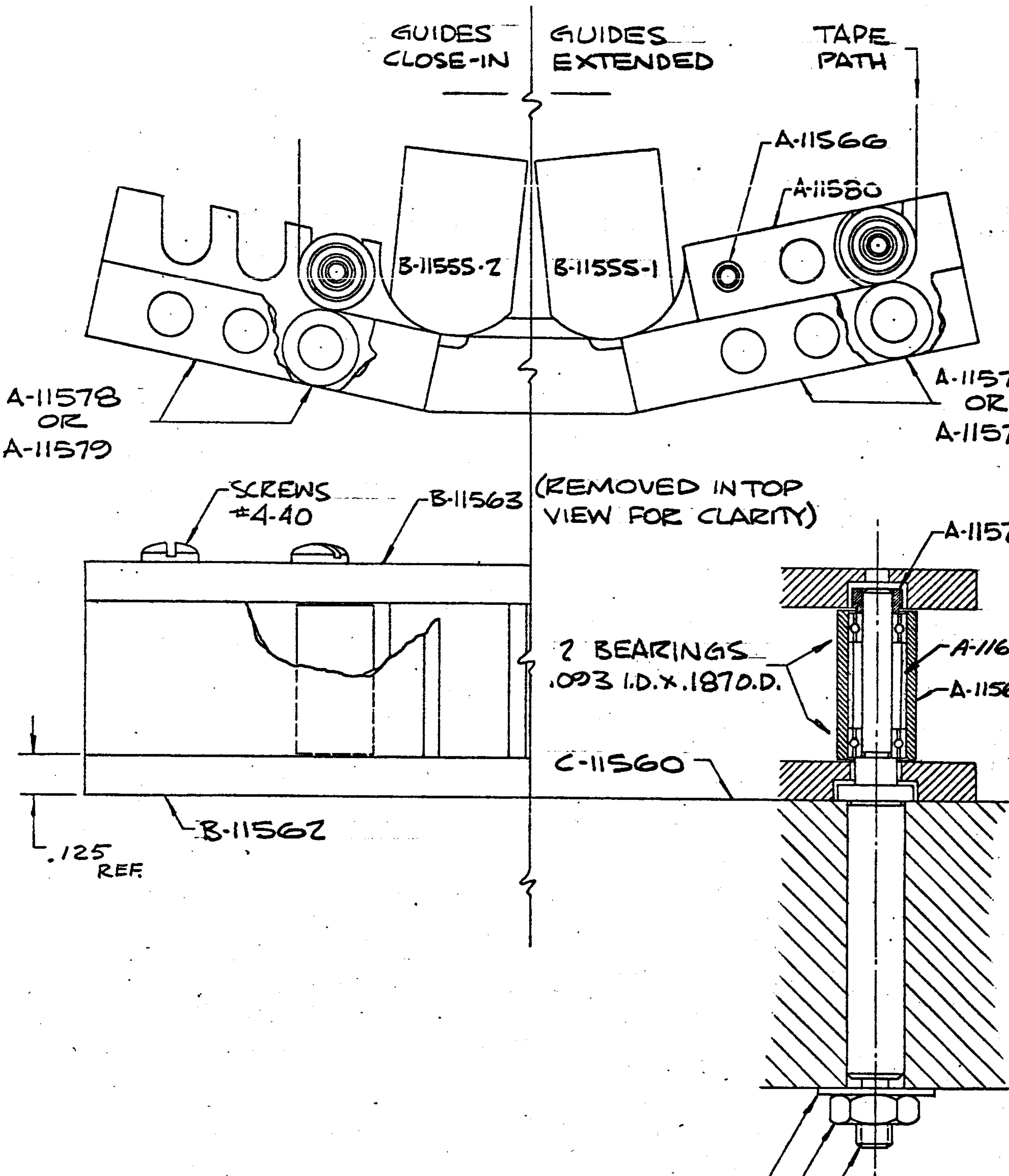
APPENDIX 7



SYSTEM D1 – TROUGH
(DOUBLE EDGE GUIDANCE PLATES
WITH FIXED GUIDES)

A-11611-7
3-30-64 R.S.K.

APPENDIX 8

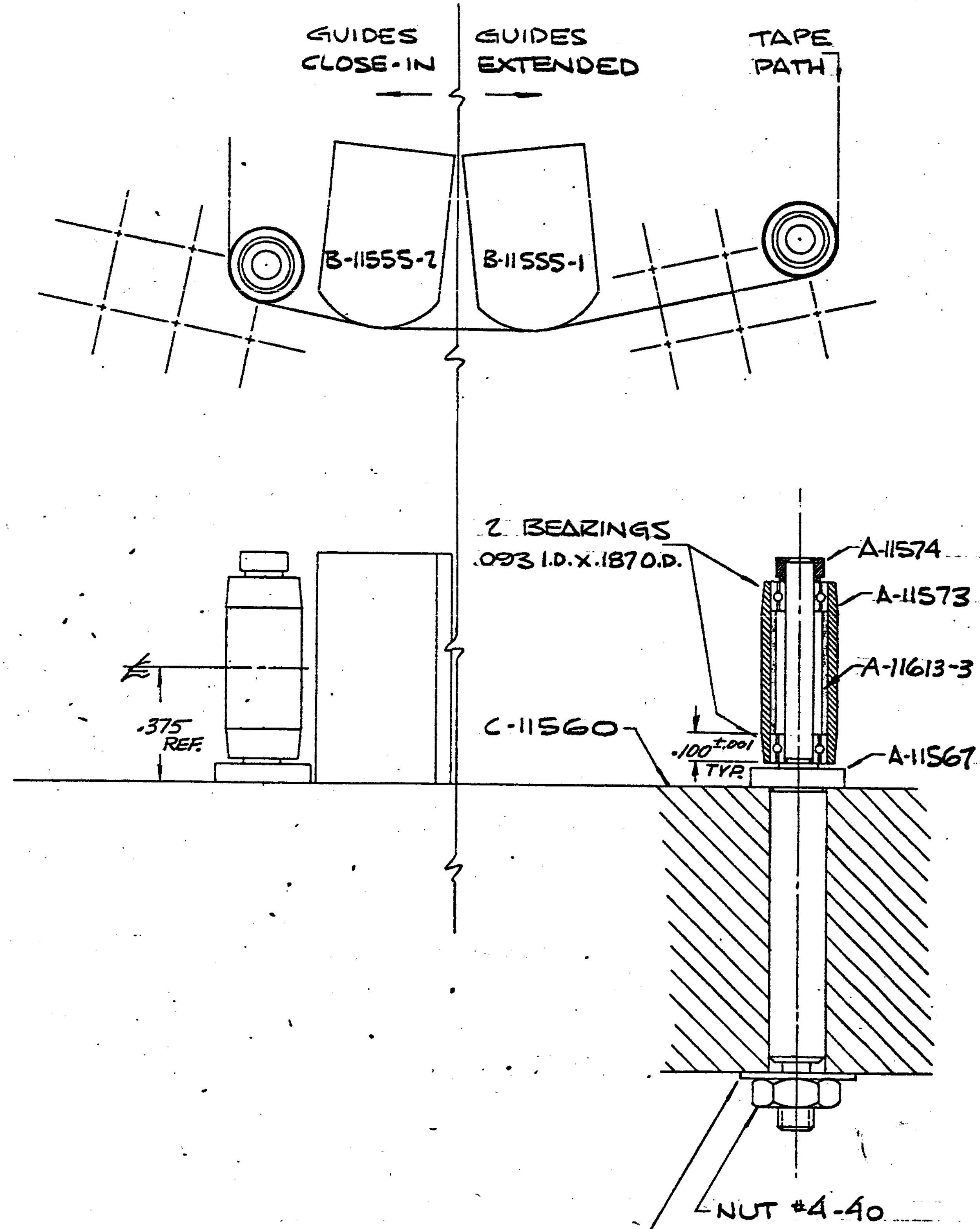


SYSTEM D2 - TROUGH
(DOUBLE EDGE GUIDANCE PLATES WITH ROLLER GUIDES)

A-11611-8

3-30-64 R.S.K.

APPENDIX 9



SYSTEM E - INTERNAL GUIDANCE (CROWNED ROLLER)

A-11611-9

3·30·64 R.S.K.