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LINEAR PHASOLVER
DEVELOPMENT PROGRAM
PHASE II

Prepared for
United States Government
Washington, D. C.

[redacted]

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SECTION 1

INTRODUCTION

1.1 SCOPE

This report describes the mechanization and test results achieved during Phase II of the Applied Research Program for developing and demonstrating the feasibility of a Linear Phasolver System for making measurements of linear motion with a resolution and accuracy ±1 micron or better.

1.2 SUMMARY

During the period covered by this report, a Linear Phasolver test fixture was designed and fabricated. This test fixture was designed to demonstrate the feasibility of the Phasolver for making measurements of linear movement with a resolution and accuracy of 1 micron or better. The electronics which was used during the Phase I portion of this program was modified to provide for a resolution of 1/10 micron. This electronics was built to provide the excitation signals for the transducer and to process and digitize the transducer output. The coarse channel which was used in the Phase I portion of the program was removed from the electronics at this time. As originally planned, the Phase II portions of this program would have used only a fine Phasolver pattern since the sole purpose of the program was to investigate the behavior of the Linear Phasolver. It was later decided that a coarse channel would be desirable, and a coarse channel was designed using a standard brush type shaft encoder and a cable drive to couple the encoder to the driver plate.

The prime purpose of this program was to demonstrate the accuracy, resolution and repeatability of the Linear Phasolver and to determine the sensitivity to variations in gap, tilt, skew and humidity.

The results obtained were encouraging, but not completely successful. A resolution of 1/10 micron was achieved quite easily. It is expected that a resolution better than 1/10 micron can be obtained by modifying the electronics to provide for a higher counting rate. An accuracy of ±1.2 microns within a single pole pair has been demonstrated. However, due to limitations in the design of the test fixture, this accuracy could not be verified over the full length of the fixture. The system exhibited a large scale error which appeared to be a function of the connections to the Phasolver plates. This scale error could be varied from +8.5 microns to -2 microns over the full length of 250 millimeters by changing the connections to the coupler. The reason for this is unknown. In addition, the scale error is nonlinear.

Unfortunately, the tests for sensitivity to gap variations, tilt and skew could not be performed due to severe pattern degradation. During the testing cycle, the patterns were damaged by dust in the environment in which the tests were performed. This dust severely scored the Phasolver patterns, requiring numerous touchups. In addition, the Phasolver pattern itself became very porous in spots due to poor quality control techniques by the vendor in applying the nickel coating used in the generation of the Phasolver pattern. Prior to the performance of the gap, tilt and skew sensitivity tests, the new experimental pattern, which had been specifically designed for use on this program, became inoperable.

Humidity tests were performed using the remaining pattern to determine the sensitivity of the Linear Phasolver to the relative humidity in the environment. This test indicated a severe sensitivity to relative humidity. However, this pattern also failed before repeatability of the data could be established and therefore the validity of the data is unknown.

SECTION 2

PHASOLVER DESCRIPTION

2.1 TEST FIXTURE

The Phasolver test fixture was designed to provide very accurate linear motion with the capability for measuring this motion within 0.1 micron. The equipment used for this program is illustrated in figure 2-1 and 2-2. To avoid the difficulties involved in building (or the cost of buying) ways of jig-bores quality, no auxiliary guiding or bearing surfaces were used except a glass guide. The driver slides with no lubrication in the corner made by the guide and the coupler. The driver is set in position approximately by hand and fine adjustments in linear motion are made with an 80 pitch screw. In the fixture, the driver is set against gage blocks. The gage blocks in turn are set against an anvil which is mounted by an elastic pantograph (parallel reed assembly). The suspension of the anvil acts as a spring as well as pantograph. Adjustable stops have been provided to protect both the leaf springs and the electronic gage head. With the electronic gage head in place, it is possible to measure the force at the null (arbitrary zero) position of the gage.

The test fixture consists of an aluminum frame which holds the two glass plates. Since all tests were performed at a constant temperature, temperature stability was not considered of major importance in the design.

The fixture was designed to allow easy dismantling of the four sides of the rectangular box which houses the coupler plate of the Phasolver. This allows removal of the coupler and guide plate when potted in the fixture. Provisions were also made for the coupler and guide plate to be secured in the fixture without potting by two rubber clutched adjust screws in front of the fixture and one at either end. This method was chosen as more satisfactory than potting the coupler. By placing ground surfaced glass spacers backed by rubber sheet spacers, the coupler and guide plate can be secured by the adjust screws. Too much tension causes the rubber clutch feature of the screws to slip, preventing damage to either plate.

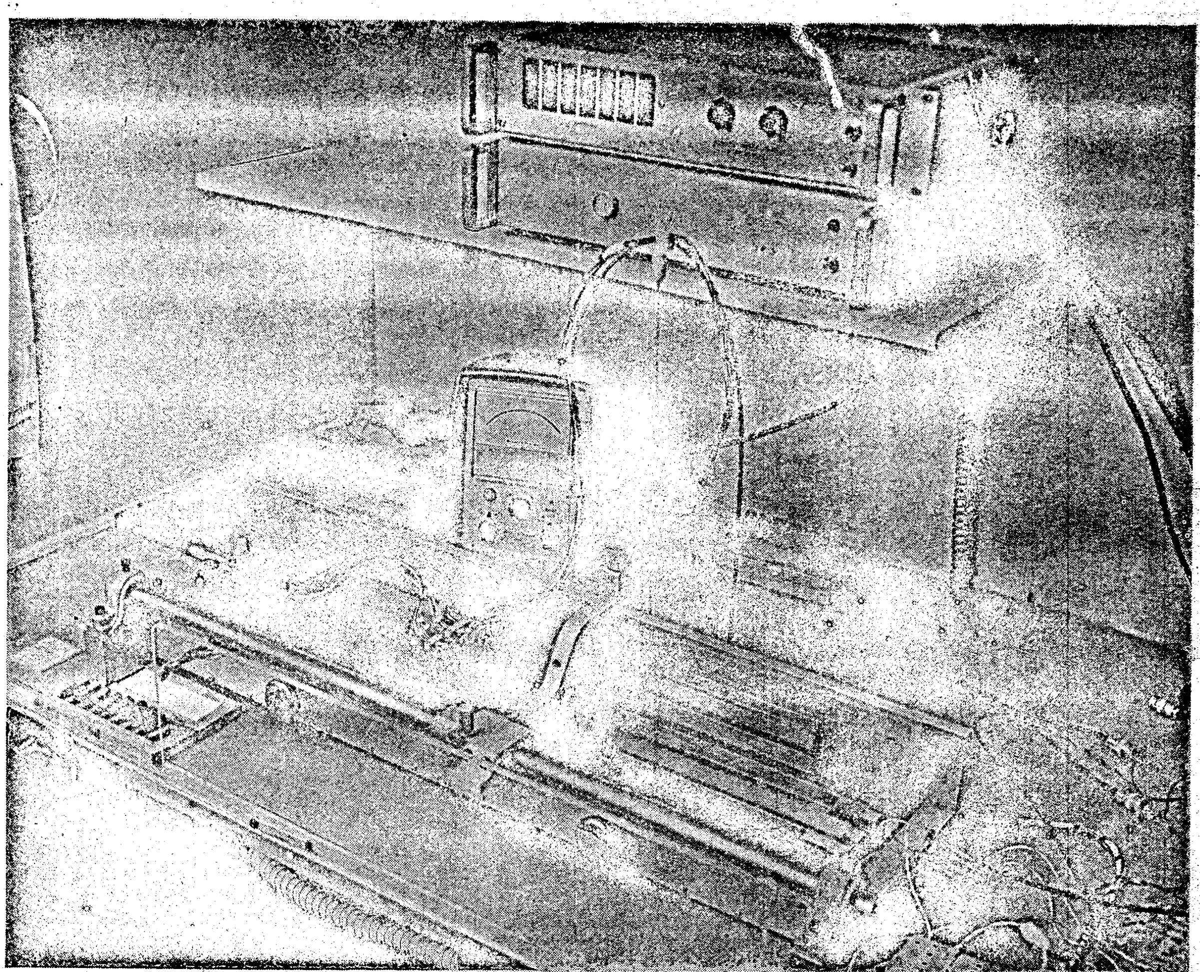


Figure 2-1. Linear Phasolver Test Fixture

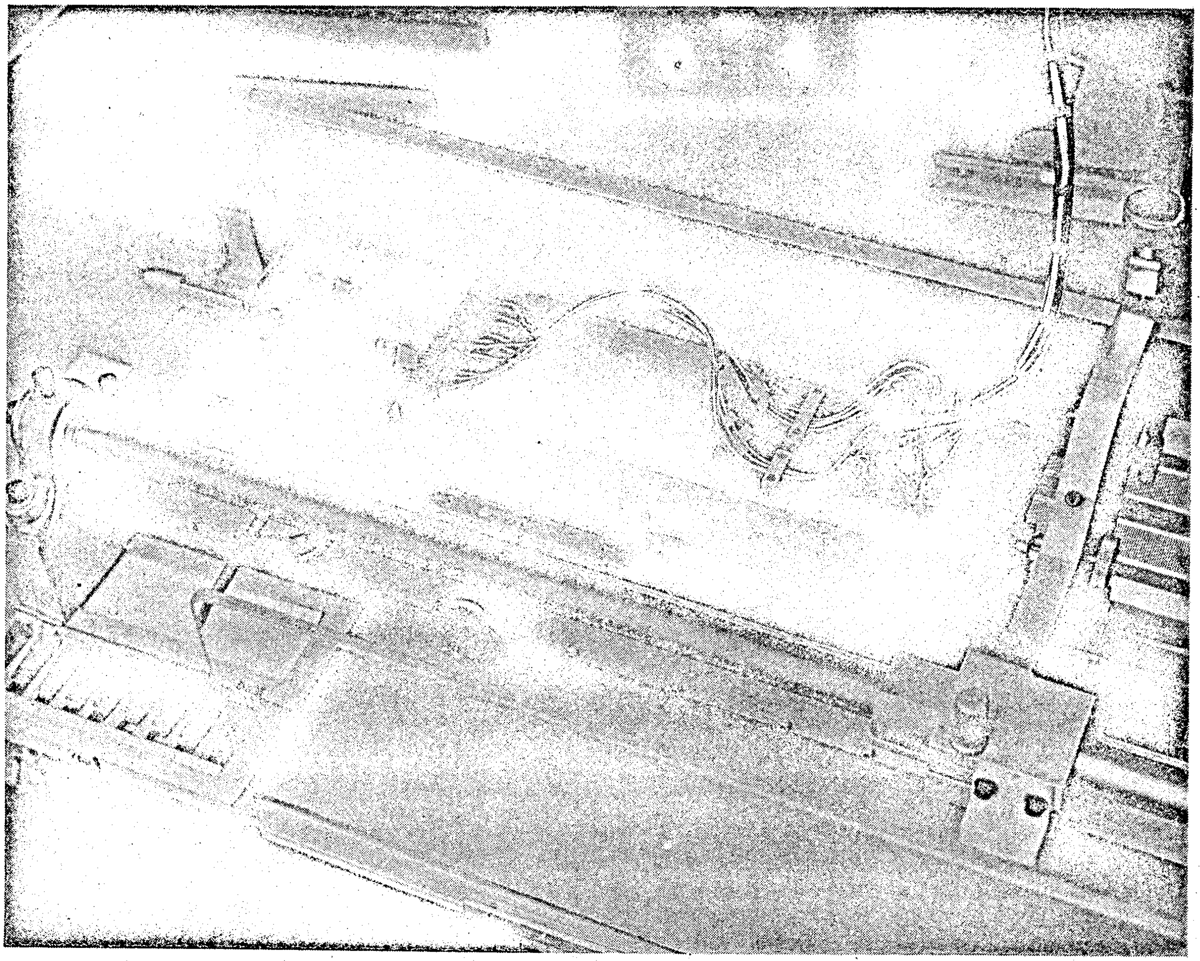


Figure 2-2.--Linear Phasolver Test Fixture Closeup

The surfaces of these two plates were optically ground to within 0.0001 in. of flatness over the entire length and were aligned in the fixture perpendicular within 0.0002 in. in breadth.

A precision ground bar extends the full length of the fixture supporting a thumbscrew released carriage containing the 80 pitch driver plate adjustment screw. A steel plate is provided at the right end of the fixture, and a magnet is attached to the 80 pitch screw carrier. It can be raised only at the right end position and is held in this raised position by the magnet.

The parallel-read assembly consists of an anvil that is cantilevered from the mounting base by four spring steel bands forming a pantograph. Provisions are incorporated on the parallel-read assembly to adjust and stop its motion by means of adjust screws.

The parallel reed assembly and millionth indicator probe are attached to a single bracket which holds those items in positive position and is attached with adhesive on the bottom to the coupler plate and in the back to the guide plate.

A hemisphere is bonded to the end of the driver which contacts with the gage block. Another spherical surface is mounted to the anvil. These hemispheres are necessary to minimize the error of incorrect alignment of the gage blocks. Initially, it had been intended that the anvil and pantograph mechanism would be used to align the gage blocks. This turned out to be unsatisfactory. Any gage blocks longer than 8 millimeters became unwieldy. The errors introduced using the anvil surface with large gage blocks is considerably greater than that possible with a spherical surface. The alignment of the gage blocks has always been a severe problem in this program. Most of the errors in repeatability can be blamed on the inability of the operator to adjust the gage blocks parallel with the direction of motion. Glass guides were fabricated to help the operator align the gage blocks parallel with the direction of motion. These guides were very helpful with the long blocks, but turned out to be ineffective with the small blocks.

2.2 PHYSICAL DESCRIPTION

The Phasolver consists of two glass plates, one of which is shorter than the other by the amount of desired motion. Parallel bands of nickel are applied to both plates and processed to provide the patterns which enable the Phasolver to perform its function. The patterns on the two plates are of different configurations and perform different functions. The patterns on one plate are utilized as the signal-drive element in the electrostatic coupling process and are designated as drive patterns. The patterns on the second plate are utilized as the coupling element in the electrostatic process and are designated as the coupler patterns.

The moving plate is the shorter of the two and has been chosen to be the driver. Provided that there is no difference in scale between the two patterns that exceeds one cycle (pole pair) over the length of the driver, and further provided that the driver ends symmetrically, the driver theoretically behaves like a single line at its midpoint. Therefore, the scale of the device should be controlled by the coupler. Interchanging the position of the coupler or the selection of which shall be the moving element should not affect the results.

The longer of the two patterns controls the scale accuracy of the device. Because it is easier to generate a coupler accurately and also easier to measure the results, the coupler was made the longer of the two patterns. In the fixture, the coupler is mounted as part of the fixed assembly and the driver slides on the coupler.

The driver slides on three adjustable delrin feet which straddle the coupler pattern. These feet can be adjusted to produce a gap from 0.0005 inch to 0.014 inch. The normal operating gap was 0.002 inch. Electrical connections were made to the driver pattern by soldering wire to thin copper shim stock and connecting the shim to the diverging lead lines of nickel from the pattern with conductive silver paint. A similar procedure was followed in making connections to the coupler plate.

2.2.1 Phasolver Driver Patterns

Two Phasolver patterns were generated in the lofting of the master. A new symmetrical pattern was developed from theoretical analyses performed which indicated that this pattern should be significantly less sensitive to skew, gap variations and tilt than a pattern with a configuration similar to the patterns used in the rotary Phasolver.

A second pattern was lofted which is very similar to the pattern used in the rotary Phasolver systems. This pattern is not symmetrical and skew tests were not planned for this pattern.

In addition to the two Phasolver patterns, a coupling area was provided to couple the output signal from the coupler back to the driver to test the feasibility of placing all electrical connections on the driver plate. The driver patterns are illustrated in figure 2-3.

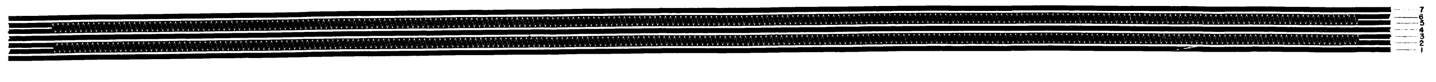
The new driver pattern consists of two identical patterns - one of which is a mirror image of the other. These patterns each consist of four sinusoidal areas phase displaced by 90 degrees. Between each sinusoidal area is a thin conductor which is electrically grounded during use and acts as a guard band to confine the electrostatic fringe fields and control their effect.

The existing phasolver driver pattern consists of two bands of conjugate sinusoidal patterns which are physically phase displaced by 90 degrees. Therefore, all four conductor areas are phase displaced by 90 degrees. In addition, guard bands separate the two conjugate patterns. This basic configuration is used on all rotary Phasolvers.

The total area of the sinusoidal portions of both patterns is approximately equal. The length of each cycle (pole pair) is exactly 1 millimeter. Each pattern consists of 254 pole pairs.

The driver pattern was generated by lofting a single, greatly enlarged, sine wave; photographically reducing the sine wave; compositing this sine wave with other sine waves in a small mask; and by a step and repeat process, photographically producing the final master pattern. This master pattern was then used to generate a photographic plate which was used in the manufacture of the actual driver pattern. The driver pattern was manufactured by vacuum depositing a thin film of nickel on the plate and photo-etching the unwanted nickel off the plate, leaving the Phasolver pattern.

NEW PHASOLVER DRIVER PATTERN



COUPLING AREA

EXISTING PHASOLVER DRIVER PATTERN

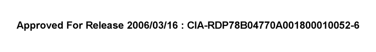


FIGURE 2—3 DRIVER PATTERNS
(2 X SIZE)

2.2.2 Phasolver Coupler Patterns

The coupler patterns used with each driver pattern are very nearly identical. Only the width is different to accommodate the different widths of the driver patterns. Each coupler pattern consists of a series of bars separated by the glass substrate. The width of each bar is 1/4 mm (1/4 the length of the corresponding pole pair on the driver pattern). The bars are exactly 1 mm apart. Therefore, each bar is aligned identically with each cycle of the driver pattern. The coupler pattern is illustrated in figure 2-4.

The coupler pattern was generated by a moving machine (ruling engine) which can very accurately generate the rectangular straight line shapes required of the coupler pattern. The coupler pattern was manufactured by coating the coupler plate with wax and cutting the desired pattern out of the wax with the ruling engine. The plate was then vacuum deposited with nickel, and the wax removed. The areas where the wax had been removed by the ruling engine were covered with nickel, and those which had been untouched by the ruling engine were bare.

2.3 FUNCTIONAL DESCRIPTION

2.3.1 Phasolver Operation

The four drive patterns are each excited by one of the four sinusoidal quadrature drive signals. The frequencies are the same but are displaced from each other by a 90-degree phase difference.

The driver and coupler plates are mounted so that the two patterns face each other, closely spaced. The relative amplitude of the drive signal which is coupled from each driver pattern is a function of the area of the driver pattern encompassed by the coupler-pattern bar. The output provided by the coupler pattern at any position is the vector sum of the coupled drive signals.

The generation of phase-shift information in response to a change in the relative position of the driver with respect to the coupler is illustrated in figure 2-5. This

FIGURE 2—4 COUPLER PATTERN
(ACTUAL SIZE)

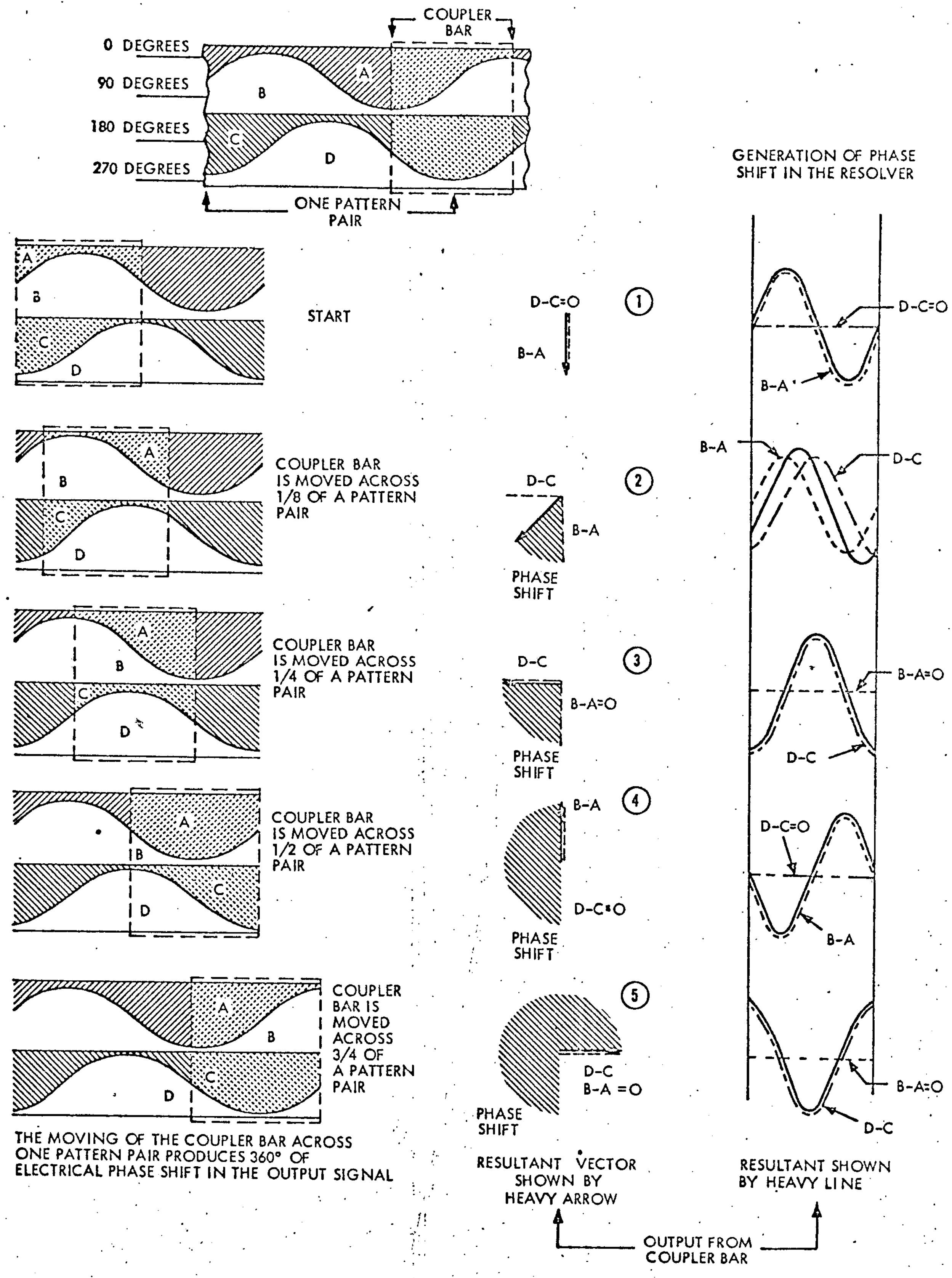


Figure 2-5. Vector Analysis of Phase Shift in a Phasolver

illustration shows only one sinusoidal segment (pole-pair) and follows the motion of the coupler-pattern bar over this pole-pair. At each progressive position of the coupler bar corresponding diagrams are shown for the vector summation of the output signal.

A minute change in the relative position of the driver with respect to the coupler varies the relative amplitude of the quadrature signals coupled from the driver to the coupler pattern. This results in a change in the vector summation and causes a change continuously from 0 to 360 degrees as the moving element moves a distance equal to one sinusoidal driver pattern. Because of the symmetry in arrangement of the pattern-pairs and coupler bars of the patterns, an average output of all pattern pole-pairs is obtained. This averaging effect results in minimizing errors introduced because of nonlinear pattern pole-pair spacing and random pattern distortions.

2.3.2 Electronics Operation

A block diagram is shown in drawing 1000-2942. The energizing frequencies for the Phasolver are derived from a countdown chain which has as its clock a Hewlett Packard Model 101A 1 megacycle oscillator which is also used to run a Hewlett Packard Model 5275A 100 megacycle time interval counter. The 1 megacycle oscillator frequency is divided by 100 to provide the 10KC energizing frequency for the Phasolver. The 1 megacycle oscillator is multiplied by 100 in the time interval counter to provide the 100 megacycle clock counter. In addition, the 10KC signal is further divided to provide a 5 cycle reset signal for the counter.

The 10KC squarewave output from the timing chain is filtered to provide the basic 10KC sinusoidal drive signal. Operational amplifiers are used to provide the phase displacements which create the four quadrature drive signals.

The output of the Phasolver is a sinusoidal signal which is displaced in time from the input signal by an increment which is a function of the linear movement to be measured. The output signal is processed through a preamplifier and another 10KC filter and then applied to a zero crossing detector and pulse shaper circuit which generates a pulse at the zero crossing of the output signal. The time interval between

Drawing 1000-2942

(furnished in separate folder)

the output stop pulse and a start pulse, which is derived from the countdown chain, is measured by the counter. This time interval is a measurement of the physical displacement of the Phasolver. Since the counter uses a 100-megacycle clock frequency and the Phasolver is energized with a 10KC frequency, the counter can resolve one part in 10,000 of the Phasolver motion. The Phasolver output rotates through 360 electrical degrees for 1 millimeter of linear motion. This provides an electrical resolution of 1/10,000 of 1 millimeter, or 1/10 of a micron.

2.3.3 Coarse Channel Operation

The coarse channel consists of a shaft encoder, a gear train, a cable drive to couple the shaft encoder to the driver plate, and a separate electronics chassis. The encoder used is a standard brush type encoder with a binary coded decimal output. The encoder is geared such that the least significant bit is equivalent to 1/10 of a millimeter of plate driver motion. The encoder is geared in this ratio so that the proper carry from the Phasolver electronics to the encoder electronics can be made.

This encoder is designed with a self-selecting "U" scan internal brush selection logic. In the normal operation of the encoder, the least significant bit brush controls the selection of the leading or lagging brushes on each track of the encoder. For the Phasolver system to propagate the carry properly into the coarse encoder, it must control the brush selection logic. This means the Phasolver system electronics must generate a signal which has the same weight as the least significant bit brush of the shaft encoder, but which switches with the accuracy of the Phasolver system. By replacing the output of this least significant bit brush with the output from the Phasolver system which has the same binary weight, the coarse encoder brush selection logic will then switch with the accuracy of the Phasolver system.

The brush selection logic of this encoder is so designed that all decades must be aligned with the least significant bit brush of the encoder. Otherwise, it is possible to switch brushes at the wrong point and obtain false results. This last restraint imposes a severe mechanical limitation on this system. Since the least significant bit signal is replaced by the Phasolver system, the alignment between the Phasolver driver and the coarse encoder must be maintained within 1/2 the linear distance corresponding to the bit or 0.002 inch of linear travel. This includes all errors in the gear train, stretch in the cable, and slippage on the cable drive pulley.

This tight mechanical tolerance is required only because of the design of the particular encoder used. Presently, the least significant decade of the encoder is used only for alignment purposes. With simple modifications to the brush block assembly and the code disc, this decade could be used. This would reduce the speed of the encoder by a factor of 10 and therefore loosen the required tolerance by a factor of 10 to 1/2 millimeter. The high cost and long delivery time associated with modifying this encoder has precluded its use on this program.

Since the encoder has a BCD code, the signal used to replace the least significant bit must have a decimal weight of 1. The only suitable digit which has this weight is the least significant bit of the most significant decade of the Phasolver word. In order to match this weight with that of the encoder, the encoder must be run at 10 times the speed. This constraint imposes the severe mechanical tolerances on the encoder drive system.

The coarse channel electronics is assembled in a chassis separate from the main electronics unit. It provides a three-digit decimal display and is designed to act as a go-between between the commercial counter, coarse channel, and a Hewlett/Packard Model 562-A digital recorder. The coarse channel electronics, in addition to decoding the coarse encoder, also assembles the entire linear Phasolver word, four digits from the Phasolver counter and three digits from the coarse encoder. The three digits from the coarse encoder are displayed on the digital readout. In addition, all seven digits are sent to the printer and printed out as a single word. A schematic of this unit (drawing 700897A) is included with this report.

Drawing 700897A
(furnished in separate folder)

SECTION 3

PERFORMANCE TESTS

3.1 INTRODUCTION

Linear Phasolver accuracy tests were performed following the Linear Phasolver Development Program Phase II Test Procedure. Portions of this procedure could not be performed due to pattern damage caused by dust particles scratching the pattern and by deterioration of the nickel coating which makes up the pattern itself. In addition, difficulties in using the gage blocks prevented measurements at all of the positions called for in the procedure. A modified procedure to incorporate these limitations is included as Appendix A.

All of the accuracy tests were performed in a special room in which the temperature could be maintained at 68° F ±1/2°F, the nominal temperature at which the gage blocks were calibrated. The relative humidity in the room was maintained at 50 percent for all tests. The room, unfortunately, was not equipped to control the amount of dust in the air and this became a severe problem.

The pattern was damaged when dust particles lying on the coupler plate became wedged between the plates as the driver plate was moved across the coupler plate. The configuration of the driver pattern is such that a single dust particle can cut a single conductive area into over 100 parts which requires extensive repair work. With a gap of 0.002 inch, it is easy to understand how this situation could occur.

After the damage was repaired, the Linear Phasolver fixture was placed in a special dust free chamber which was installed inside the controlled temperature room. This significantly reduced the amount of further pattern damage due to dust scratches. This chamber was also used to perform the humidity tests.

Deterioration of the Phasolver pattern was caused by poor vacuum deposition of the nickel coating prior to the application of the Phasolver pattern. If proper controls on the nickel deposition process are not maintained, large pinholes appear in the nickel which after some period of time increase in size due to lack of adhesive quality around the perimeter of the hole. This is a critical process in the manufacture of Phasolver discs and receives considerable attention by [redacted] STAT

STAT [redacted] personnel during the normal manufacturing process. Unfortunately, the generation of the coupler plate was beyond the capabilities of our present vendor and both the coupler and driver plates were fabricated by another company. [redacted] source inspection was not available since the new vendor was not a local concern.

When the damage was found, repairs were attempted using conductive silver paint of the type that was used to make connections on the coupler and driver plates. Not all of the repair work was successful. In some places, the area to be repaired was a cut in the pattern possibly only 2 to 3 thousandths of an inch long. The area of the cut usually was not significant, but in many cases the cut separated a significantly large portion of the pattern. In most cases, only a tiny spot of conductive paint was applied to bridge together the two portions of the pattern that had been damaged. In the areas where the pattern had deteriorated, the paint was again used solely to regain connections to areas which had become disconnected.

A large amount of difficulty was encountered in obtaining repeatability, using the test fixture as it was originally designed. A minimum number of gage blocks were bought for use with the fixture. It had been planned that these blocks would be rung together to obtain the different lengths that were wanted. This approach was taken because of the large expense entailed in the purchase of these blocks. It had been planned that with a total quantity purchase of 14 blocks, different combinations of blocks could be made which would completely define the operation over the full length of the pattern. Shortly after the tests started, however, it became obvious that, using this approach, the heat input to the blocks from the operator's hands and the friction generated during the ringing operation made it impossible to obtain repeatable results. Gloves and tongs were used to isolate the operator's body heat from the blocks. This technique helped, but was not sufficient to eliminate the uncertainty. This severely limited the testing that could be performed with the blocks on hand. The original plans called for measurements within the pole pair at three points on the patterns: at 7 millimeters, 132 millimeters and 257 millimeters. This had to be dropped and all measurements within the pole pair were made at 7 millimeters. In addition, measurements were planned every 15 millimeters over the length of the pattern. This plan also had to be dropped. The data that was obtained, therefore, is not complete. However, the data shows very definitely the capabilities of the Phasolver system, as far as resolution and accuracy over small distances. The lack of ability in using the gage blocks as originally intended reduces the amount of data that is available for accuracy over long distances. However, the goal of determining the operation of the Phasolver has definitely been met.

3.1.1 System Resolution and Repeatability

From the very beginning, the Phasolver easily met the requirement of 1/10 micron resolution. This resolution appears to be limited only by the electronics and not by the Phasolver. The electronics as designed is not capable of measuring to a finer resolution. This feature was demonstrated by comparing the Phasolver to the millionths indicator and showing that the system could easily resolve the 1/10 micron. As mentioned earlier, considerable difficulty was encountered while trying to obtain reasonable repeatability due to the problem of expansion of the gage blocks. Using single gage blocks, however, repeatability in the order of 0.1 micron has been achieved.

3.1.2 System Long Term Stability

A constant and unresolvable problem has been linear instability. Either the millionths indicator or the Phasolver or both appear to drift with time. Overnight, the millionths indicator moved off scale (typically greater than 2-1/2 microns) while the Phasolver moved less than 1 micron. When the Phasolver was then moved until the millionths indicator again read 0, the Phasolver count exhibited a significant change from the previous zero reading. Differences of 3 to 4 microns were common. Some differences were as large as 9 microns. Tests on the millionths indicator have shown no significant drift when installed in a special test fixture to measure this drift. The unit was also replaced with no effect. During the humidity test, the millionths indicator reading was changing while the Phasolver reading remained constant. It is important to note that when these tests were being made, the Phasolver was being pressed against the pantograph mechanism spring and the indicator was acting as a force gage to measure the force upon the indicator probe so that the same force could be maintained at all times. In the condition just described, the Phasolver driver is significantly more massive than the indicator probe tip, and it seems unlikely that the Phasolver could be moving as much as the indicator probe indicated, and in such a manner that the Phasolver count did not move.

During accuracy tests on the new pattern, it was observed that the Phasolver count changed with the indicator remaining constant. This situation, however, was accompanied by other instabilities which indicated that the instability was due to the Phasolver pattern itself. The situation is believed caused by the severe degradation of the new pattern at the time. This particular instability was not present with the existing pattern.

On occasion, for short periods of time, an instability would be noted where the Phasolver zero reading would not repeat to the same point. On comparing the balance prior to and after this happened, no difference was found in the condition of the balance. All of this data indicates that there is a mechanical instability somewhere in the test fixture rather than the Phasolver, which severely limits the creditability of any long term data.

3.1.3 Scale Error Correction

Errors in the scale of the coupler pattern due to lofting errors or temperature changes are a primary source of large errors. Early in the program, a method of correcting this error was devised which, it was thought, would enable this error to be eliminated electrically. Circuitry to test this technique was built and the scheme was evaluated. It was found to be unsatisfactory.

The technique was based on changing the scale relationship between the least significant bit of the Phasolver word and the length of the Phasolver pole pair. An error in the scale of the device will stretch or shrink all of the pole-pairs alike. If the Phasolver counter clock is used to generate the energizing signals for the Phasolver, the modulus (the total count corresponding to a pole-pair) is fixed regardless of how the clock frequency varies. If, however, the counter clock is different from that used to generate the energizing signals, it is possible to vary the modulus and cause each count to have a slightly different scale value.

For this purpose, a 1 mc variable oscillator was used to change the energizing frequency of the Phasolver signals. A separate 1 mc crystal controlled oscillator was used as the counter clock.

In a single pole-pair, this technique did indeed vary the scale. However, the Phasolver output phase shift recycles to zero at the beginning of each pole-pair. This forces the Phasolver counter to zero. If the modulus is such that it does not recycle to zero synchronously with the pole-pair output (as would be the case if the modulus were to be changed), the readout produces false data. For example, if the modulus is adjusted to be smaller than normal (as if the pattern were shrunk), the Phasolver counter will recycle to zero before the register is full thereby eliminating some combinations of numbers. If, on the other hand, the modulus is adjusted to be larger than normal, the Phasolver counter will recycle once when the register is full and again when the Phasolver phase shift recycles to zero. This allows some numbers to be repeated in the same pole-pair. Since the counter recycles as a function of the Phasolver pole-pair length, the scale correction is only valid for small distances within a single pole-pair.

3.2 Co/Cv DETERMINATION

The Co/Cv ratio is the ratio of the fixed capacity to the variable capacity of each of the sinusoidal areas which make up the Phasolver pattern. It is analogous to the signal to noise ratio in other systems. In a theoretical Phasolver, the effects of Co cancel, leaving only the effect of Cv in the output. Theoretically, the Co/Cv ratio can have a value no less than 2. On existing Phasolvers, this value ranges anywhere from 5 to 14 and is strongly dependent upon the gap between the plates. As the Co/Cv ratio increases, the allowable tolerances on drive amplifier drift and gap variations become tighter since the fixed capacity errors become more significant.

Figure 3-1 illustrates the Co/Cv ratio of each of the Linear Phasolver patterns as a function of gap. It is obvious from this graph that the existing pattern has a significantly better ratio than the new pattern. Examination of the new pattern also shows that the Co/Cv ratio of conductive areas 10 and 25 is significantly higher than that of the remainder of the areas in the new pattern. The effect of this discrepancy is to seriously effect the accuracy of this pattern with perfect drive signals. As shown in figure 2-3, the Linear Phasolver Driver pattern, areas 10 and 25 have the same phase relationship. The effect of this discrepancy is that the static portion, Co, of this pattern will have a disproportionate effect on the output and the Co's will not effectively cancel. This seriously disturbs and reduces the accuracy of this pattern.

A number of tests were performed to determine the nature and cause of this discrepancy. As yet, no satisfactory hypothesis has been generated that can be easily proved. The areas of the patterns were measured on a Mann Mono-Comparator, Model 422-C. The results were run through a Packard-Bell PB-250 computer, and were found to be

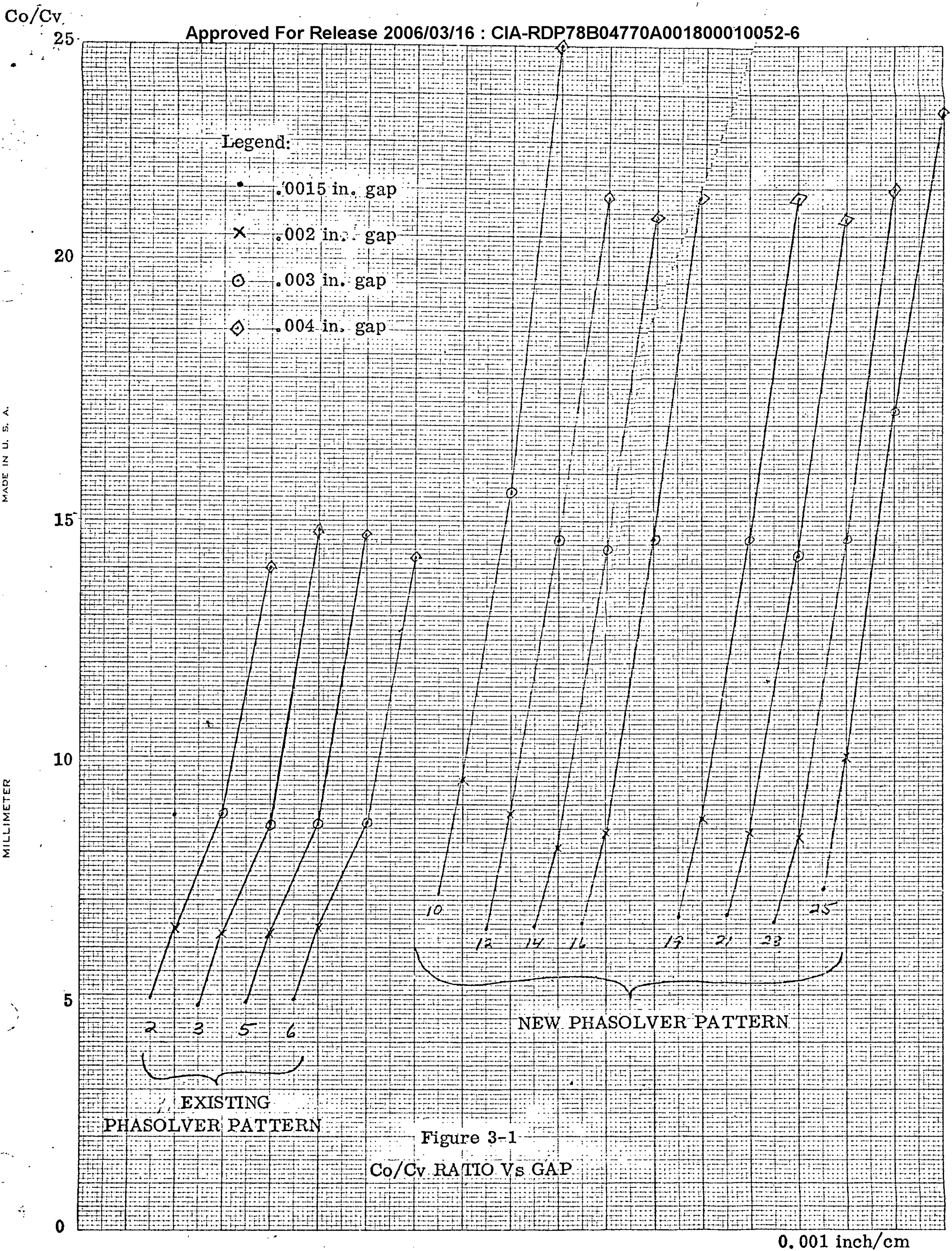


Figure 3-1

Co/Cv RATIO Vs GAP

almost identical. Any differences between patterns were much smaller than the discrepancies indicated by the variation in this ratio. One hypothesis that appears to have merit is the following:

Each of the driver areas of this pattern is surrounded on both sides by a grounded guard band. The nickel pattern on this plate is very thin and consequently the electrical resistance is quite high. This is especially true of the guard bands since they are only 0.005 inch wide. Electrical contact was made to these patterns on only one end. Therefore, it is possible for the guard band to pick up some of the signal that is impressed on the drive area and re-radiate this to the coupler. The drive signals have been observed with an oscilloscope on the guard bands at the far end from their connections. Guard bands 9 and 26 have a pattern on only one side. Therefore, they are more likely to pick up signals from areas 9 and 25 than guard band 24, which, during this test, had the area on one side grounded while the pattern on the other side was energized. Unfortunately this hypothesis cannot be proven without generating another pattern. The effect of this unbalance, however, has been seen during the test on this pattern with perfect quadrature signals.

A second hypothesis which takes into account information gathered on later tests is as follows:

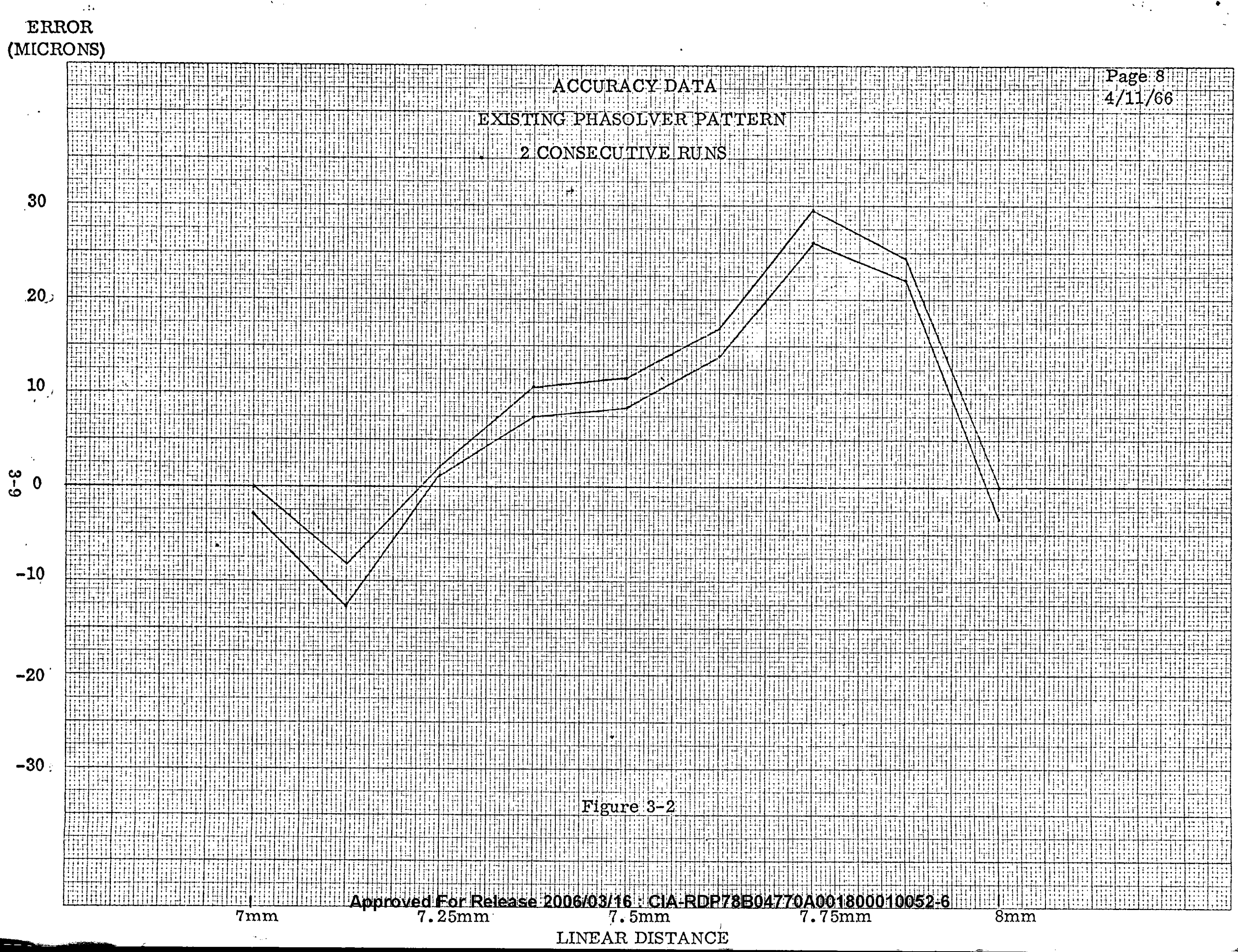
The Co/Cv ratio is the ratio of the fixed capacity to the variable capacity, or in other terms, the ratio of the fixed area to the variable area. Any increase in the fixed capacity would cause this ratio to be increased. The fixed capacity could be increased by an increase in a non-sinusoidal portion of the pattern. It could also be increased by uncontrolled coupling of the drive signal to the coupler external to the pattern. The method by which the electrical connections were made to the pattern is significantly different on this system than has been used on any other Phasolver system. In this system, the connections are made by connecting the drive wires to the side of the driver plate opposite to the pattern and running conductive material around one end of the driver plate and making connections to the pattern. The spacing of the connection lines running along the plate could not be made symmetrical to the pattern because of space limitations. During the accuracy tests on the new pattern, with the output signal coupled to the driver, it was noted that a sizeable output signal existed on the coupling area with the driver plate lifted completely off the coupler plate. Tests showed that the energy from the drive lines and the conductive material along the end were coupling directly to the coupling area. By moving the wires slightly, the magnitude of the output signal could be dramatically changed. It is possible that some of the energy in these conductors was unevenly coupled to the coupler bar due to this non-symmetry. Again, this hypothesis cannot be proven without modifying the driver plate to accept connections on the end of the plate close to the driver pattern and supplying the input to the driver with shielded drive lines.

3.3 ACCURACY WITH EQUAL AMPLITUDES AND PHASE QUADRATURE DRIVE SIGNALS

3.3.1 Existing Phasolver Pattern

The accuracy data of the existing Phasolver pattern with perfect drive signals is shown in figures 3-2, 3-3, 3-4, 3-5 and 3-6. The data in figures 3-4, 3-5, and 3-6 was taken prior to the pattern damage as noted earlier in this report. The linear distances indicated on the graphs were obtained by ringing together appropriate gage blocks to obtain the desired distances. Figure 3-4 was obtained by ringing together the 15 millimeter block first with the 7 millimeter block and then with the 7 1/8 mm block, the 7 1/4 mm block, etc. Figure 3-5 was obtained by ringing together in the same manner the 7 mm, 7 1/8 mm, etc. blocks with the 125 millimeter block. Correspondingly, in figure 3-6, the 7 mm block was run consecutively together with the 250 mm block. Figures 3-4, 3-5, and 3-6 were each composed of four consecutive runs. The vertical lines at each data point indicate the spread of the data of the four runs. As is evident from these curves, as the distances became larger, the uncertainties at each point became larger. For example, the worst case uncertainty in figure 3-4 is 1 micron. In figure 3-5, the worst case uncertainty is 4 1/2 microns at one point. In figure 3-6, the uncertainty is 5 microns at every point.

The increased non-repeatability as the distance increased indicated that measurements taken over long distances by ringing blocks together was not a satisfactory arrangement. Accordingly, after the patterns were repaired, the data was again repeated using single blocks by themselves. This data is shown in figures 3-2 and 3-3 and shows a significant difference in the data. However, the drive signals had been adjusted since the first runs were made and the starting point in the pole pair had been changed to correspond electrically with the reference drive signals. Figure 3-2 also shows one other interesting facet - 2 runs were made, one following the



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ACCURACY DATA

EXISTING PHASOLVER PATTERN

2 CONSECUTIVE RUNS

Figure 3-2

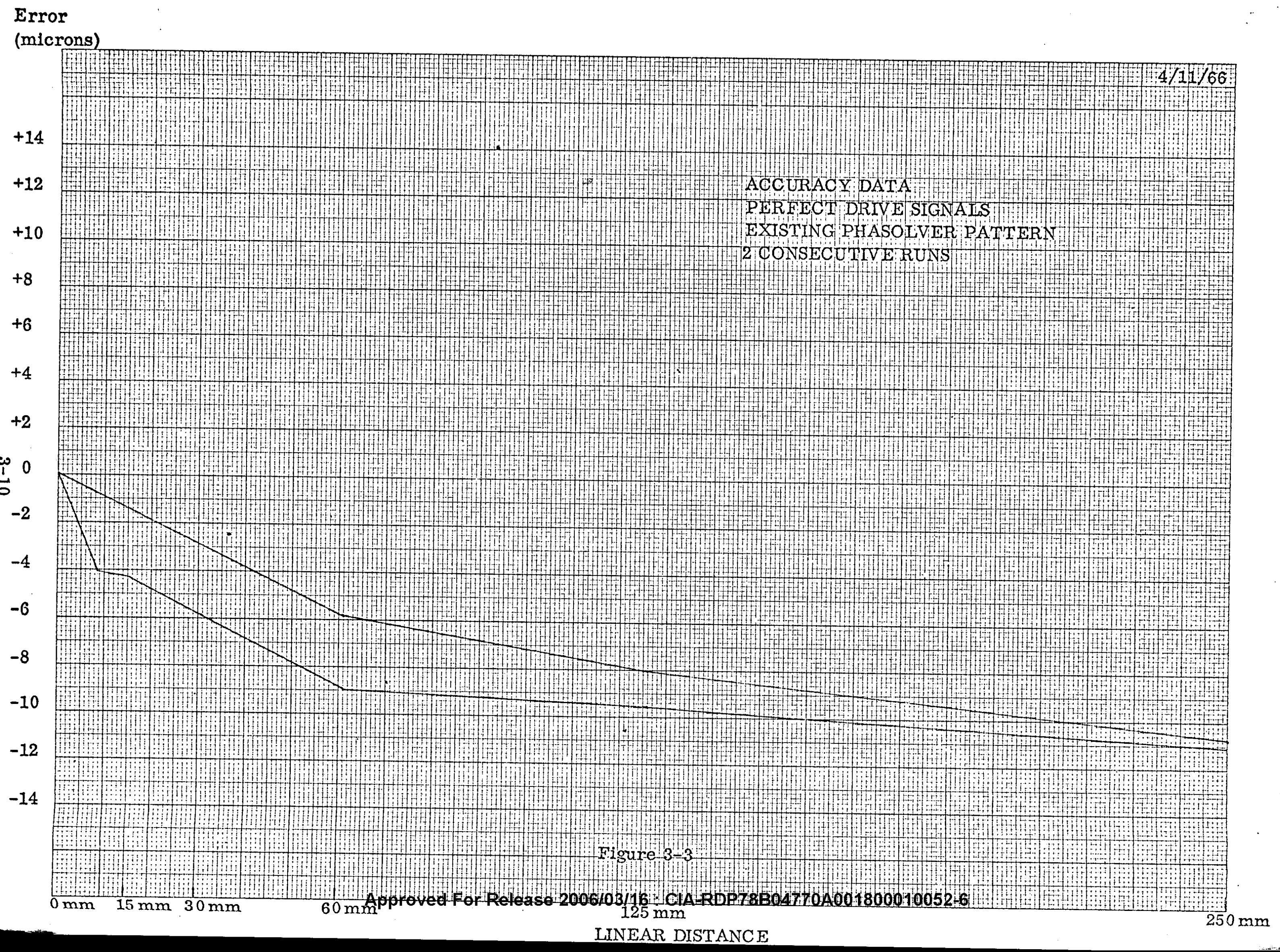
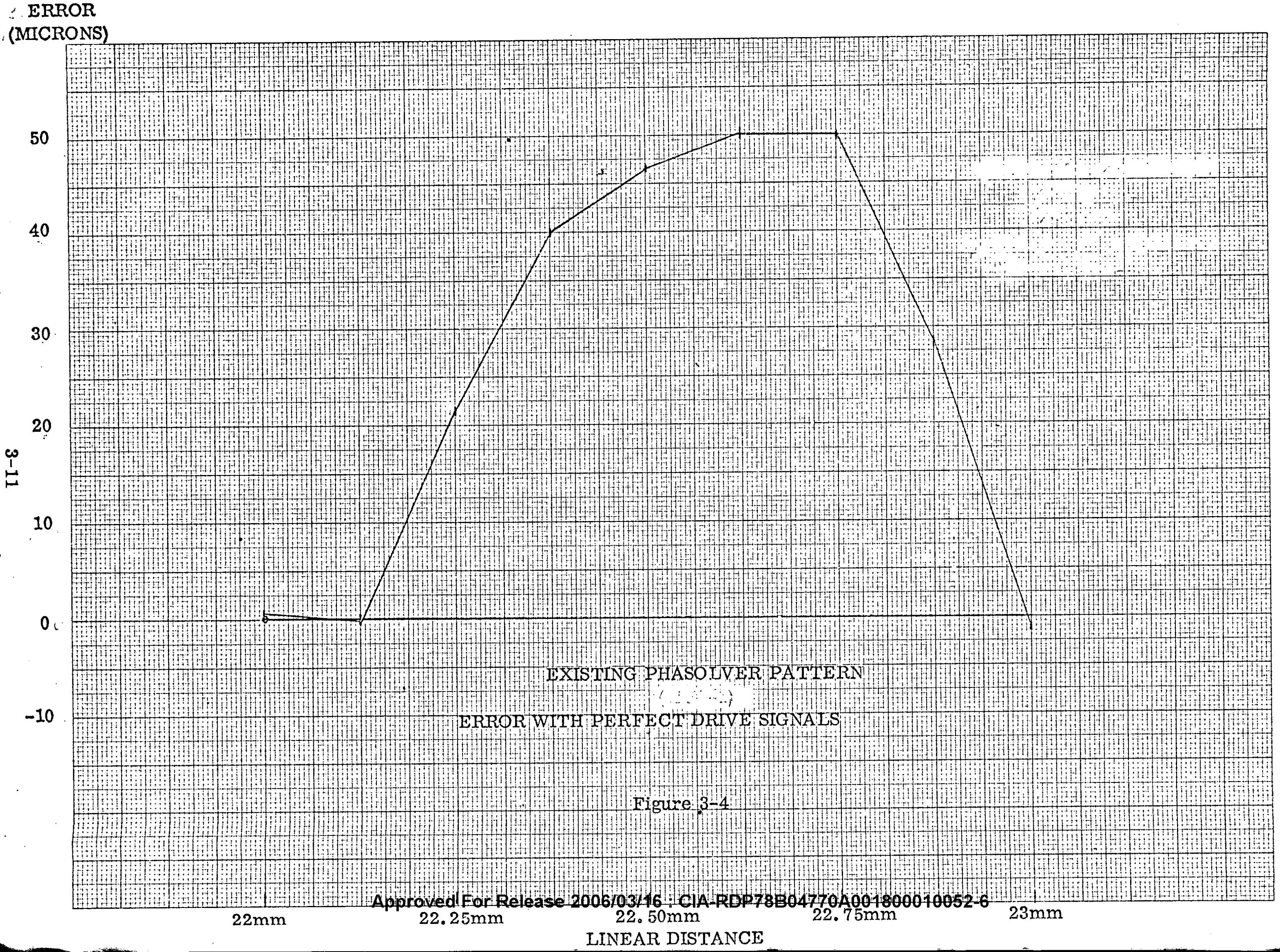

Error
(microns)
4/11/66
+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
-12
-14
ACCURACY DATA
PERFECT DRIVE SIGNALS
EXISTING PHASOLVER PATTERN
2 CONSECUTIVE RUNS
0 mm
15 mm
30 mm
60 mm
125 mm
250 mm
LINEAR DISTANCE

Figure 3-3

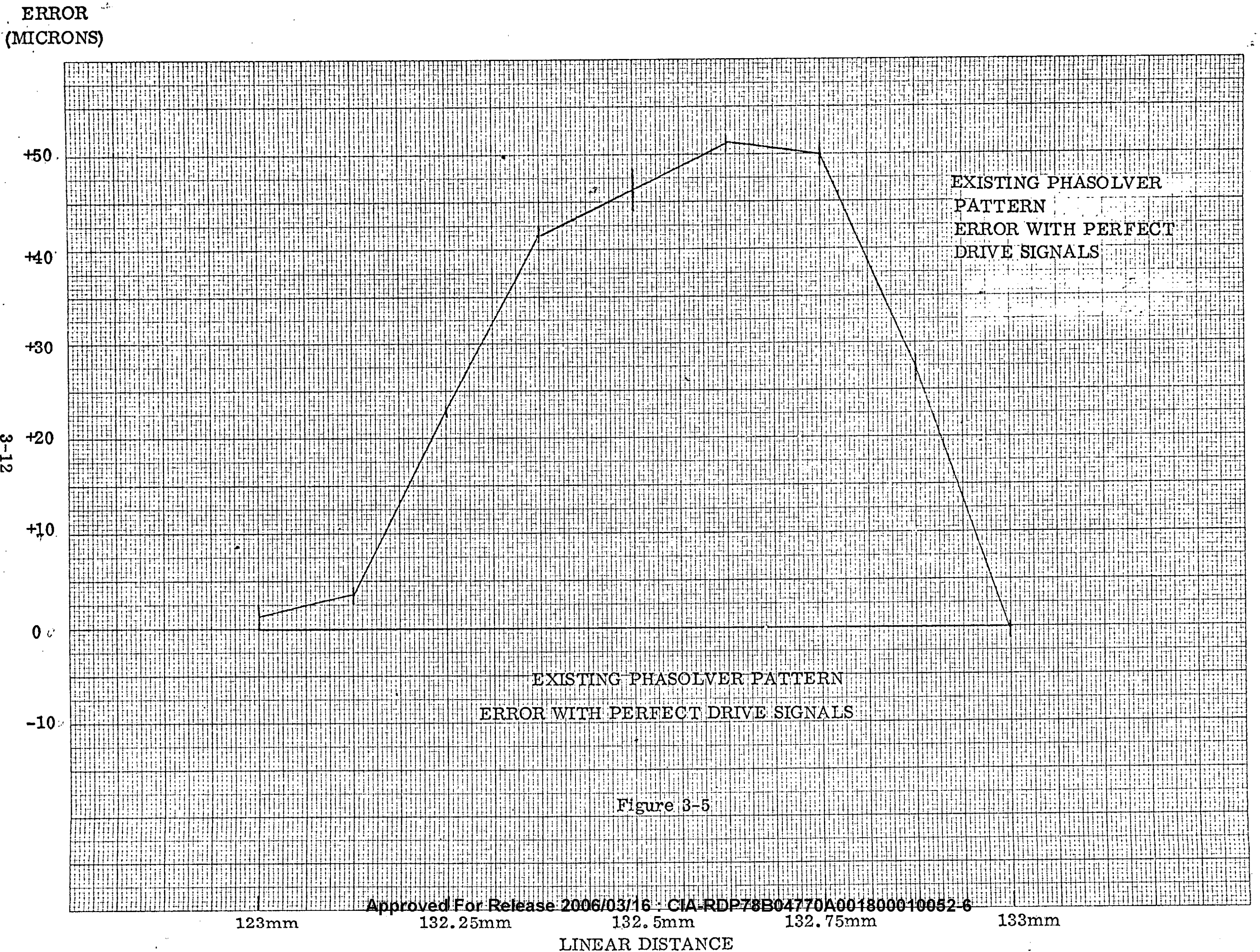


EXISTING PHASOLVER PATTERN

[redacted]

ERROR WITH PERFECT DRIVE SIGNALS

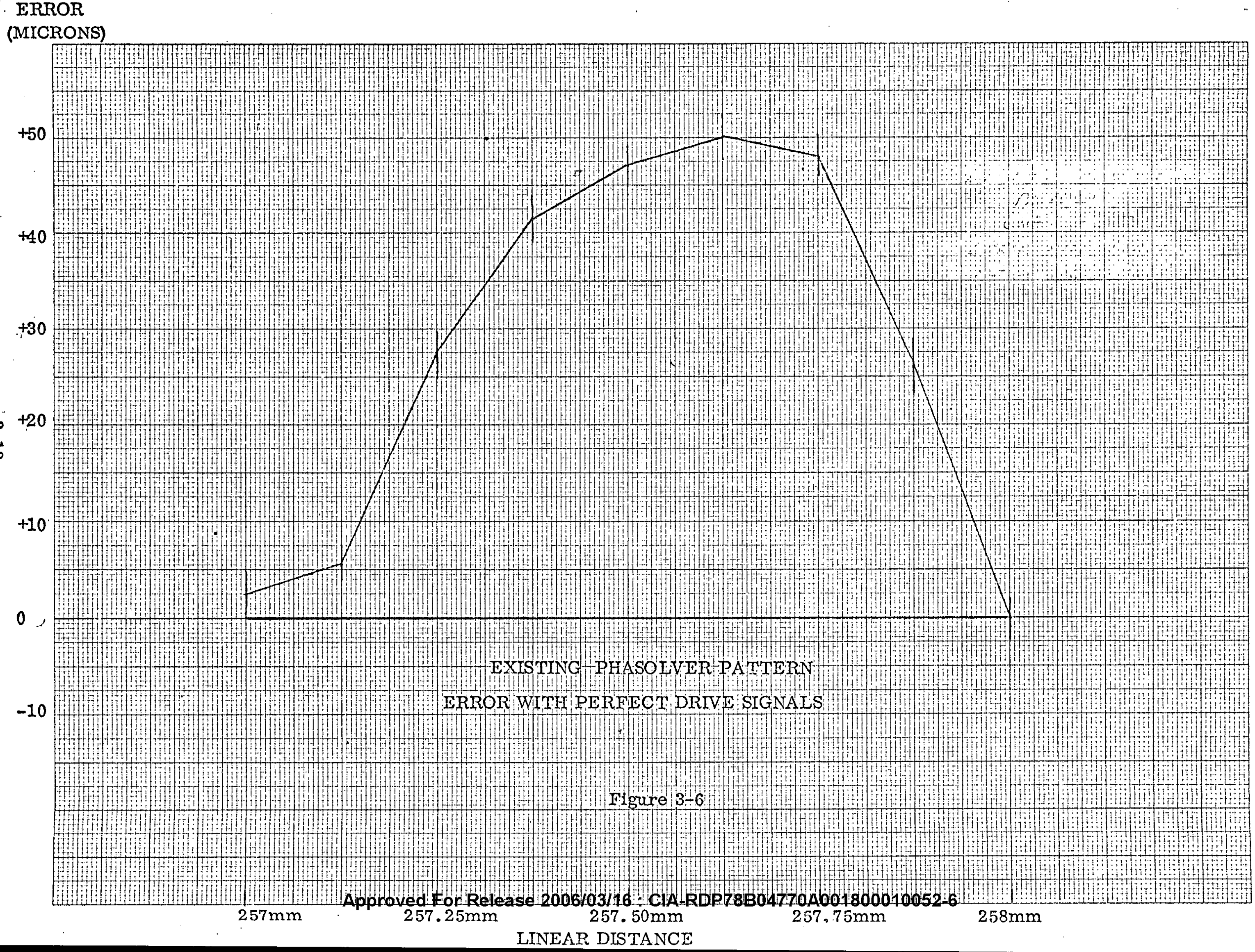
Figure 3-4



EXISTING PHASOLVER PATTERN

ERROR WITH PERFECT DRIVE SIGNALS

Figure 3-5



EXISTING PHASOLVER PATTERN

ERROR WITH PERFECT DRIVE SIGNALS

Figure 3-6

other almost immediately. A negative shift occurred between the two runs, yet the balance data looks almost identical. The repeatability of each point was measured during each run and found to be less than 0.4 micron. Figure 3-3 shows the scale error of these two runs. It appears that in the area from 7 mm to 60 mm, only the zero point has changed. The slopes are all constant.

3.3.2 New Phasolver Pattern

Figures 3-7, 3-8 and 3-9 show the accuracy of the new Phasolver pattern as a function of perfect drive signals. This data was taken in the same manner as the data on the existing Phasolver pattern and shows a similar type of error. This data could not be repeated after the patterns were repaired since sufficient pattern damage had occurred that it was not possible to obtain a phase shift from the new pattern after repairs. A comparison of the error curves of both patterns shows that the nature of the error is a single cycle of approximately 45 microns peak-to-peak with the new pattern and 50 microns peak-to-peak with the existing pattern. This is considerably in excess of that predicted for the new Phasolver pattern based upon the analysis which was used to generate the new pattern. However, the large Co/Cv discrepancy which was measured earlier may explain this large error. The existing Phasolver pattern shows the same type of error and even larger magnitude than the new pattern and yet has no significant Co/Cv unbalance. This indicates that the existing Phasolver pattern configuration has some serious drawbacks which are not evident in the new pattern.

3.4 BALANCE ACCURACY AND TEST REPEATABILITY

3.4.1 Existing Phasolver Pattern

The existing Phasolver pattern was phase balanced with the output signal taken from the coupler. Balancing is defined as the adjustment of the drive signals to obtain a linear phase relationship to mechanical motion. Balancing is performed to compensate for pattern irregularities, systematic pattern errors, and uncontrolled coupling from the drive signals to the Phasolver output. Two types of balancing techniques are used.

a. Phase Balance

b. Amplitude Balance

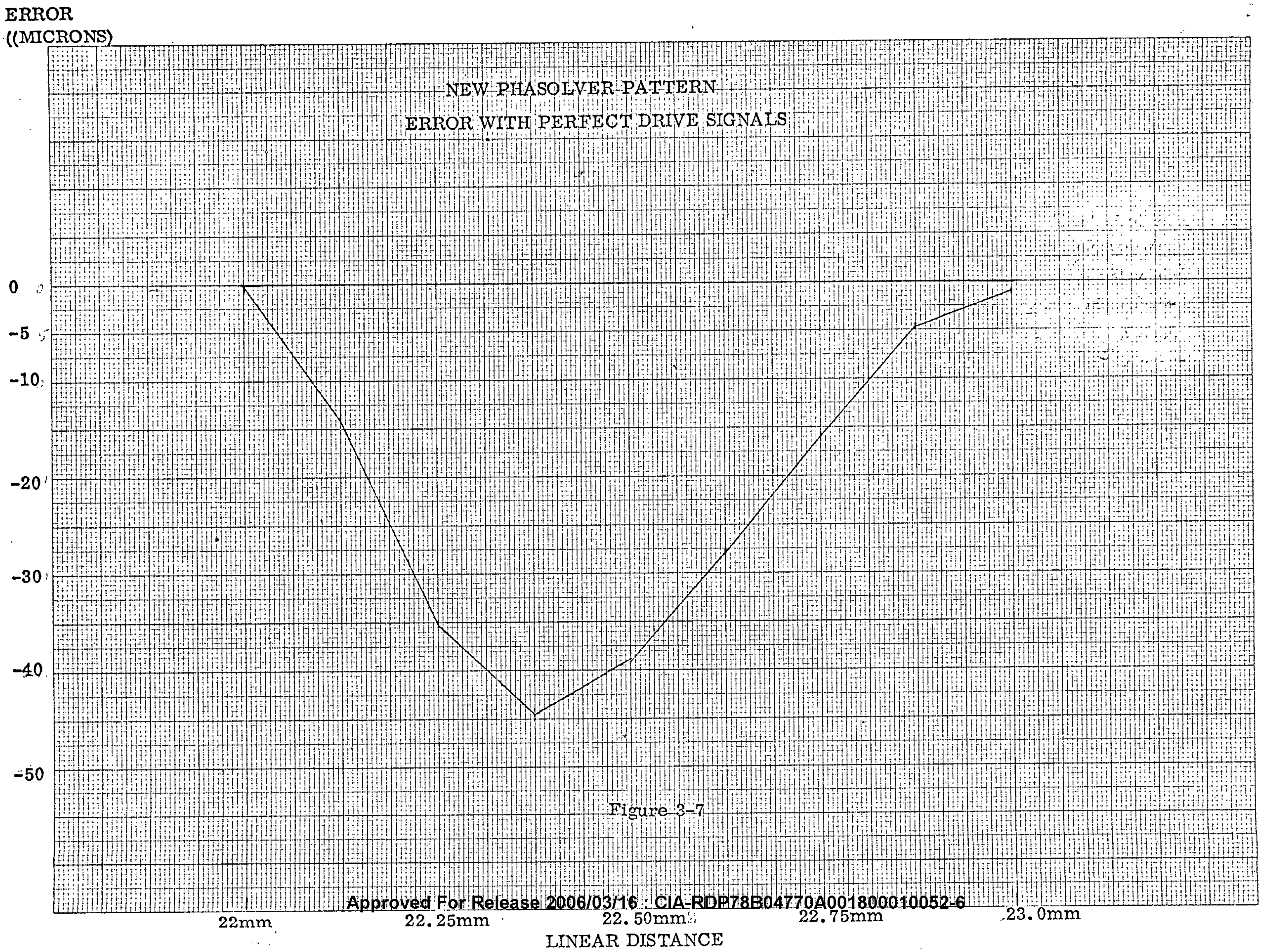
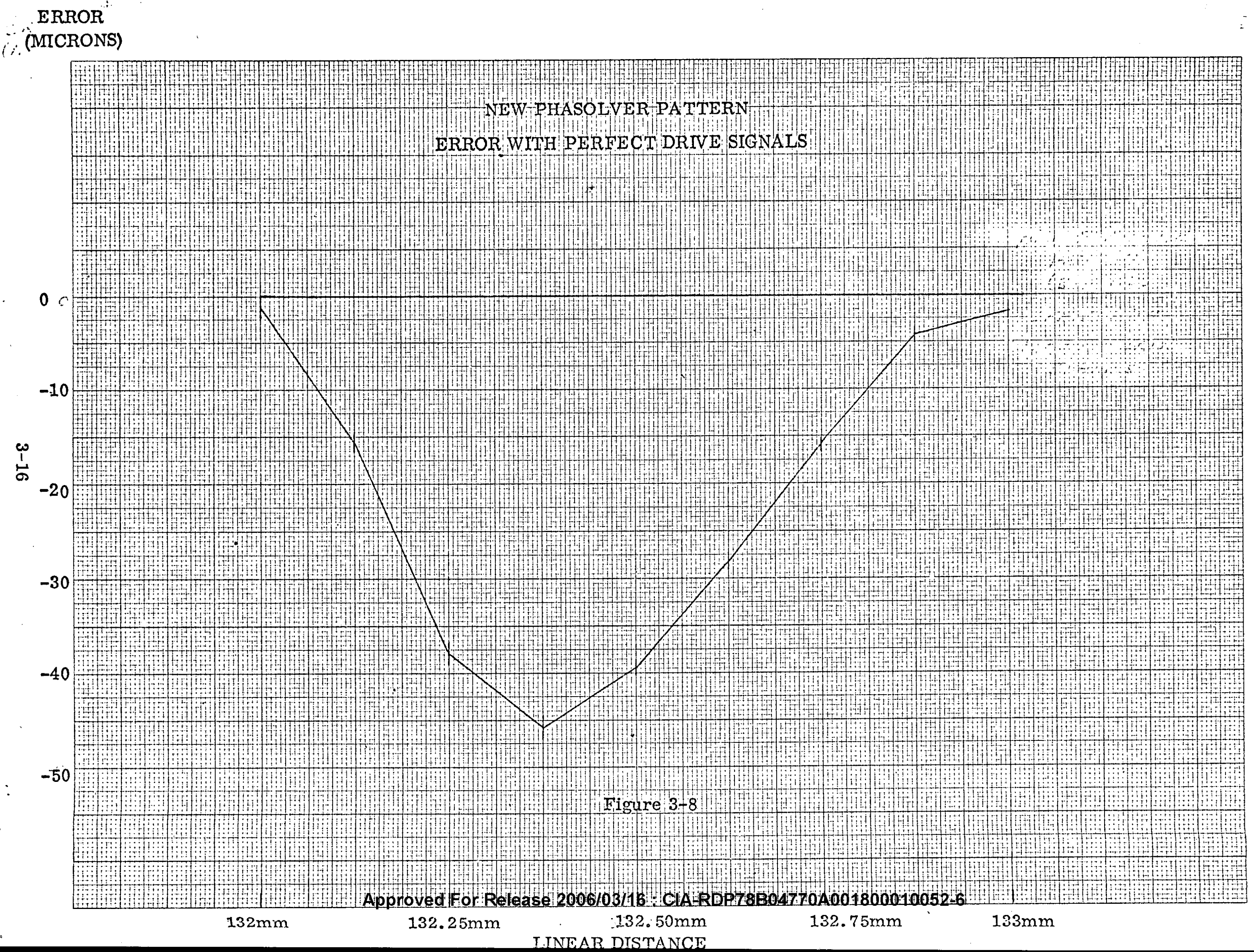

ERROR
((MICRONS)
NEW PHASOLVER PATTERN
ERROR WITH PERFECT DRIVE SIGNALS
0
-5
-10
-20
-30
-40
-50
22mm
22.25mm
22.50mm
22.75mm
23.0mm
LINEAR DISTANCE

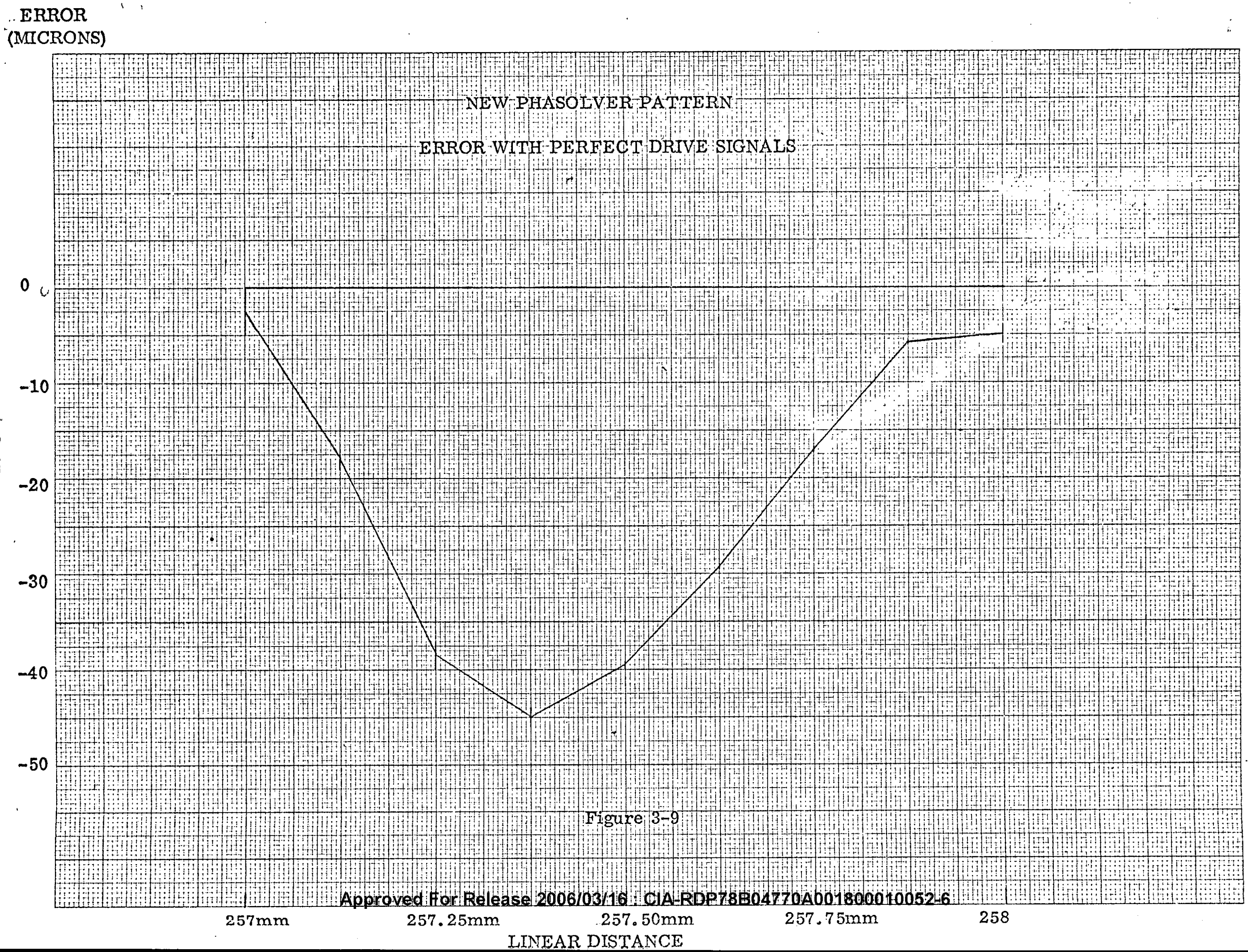
Figure 3-7



NEW PHASOLVER PATTERN

ERROR WITH PERFECT DRIVE SIGNALS

Figure 3-8



NEW PHASOLVER PATTERN

ERROR WITH PERFECT DRIVE SIGNALS

Figure 3-9

The phase balance procedure calibrates the phase shift output of the Phasolver against a known standard. The drive signals are adjusted so that, at the eight intercardinal points in the pole pair, the error is minimized.

The amplitude balance procedure adjusts the drive signals so that the output of the Phasolver has a constant amplitude as is predicted by the Phasolver theory. There is a very close correlation between amplitude balance and accuracy. However, for the most accurate measurements, the phase balance is preferred.

Figure 3-10 shows the interpole-pair accuracy data within the pole pair from 7 millimeters to 8 millimeters. After balancing, the output signals were taken from the coupler in a number of different positions in an effort to determine the mechanism of the large scale error which had been noted earlier. Cables were attached to both ends of the coupler pattern and connected to a switch. The output of the switch went to the electronics unit. In addition, the center of the coupler pattern was connected to the large coupling area on the coupler plate with conductive paint and another lead was taken from the coupling area to the switch. By changing the switch position, it was possible to connect the various parts of the coupler together and connect any point or combinations of points of the coupler to the electronics. Figure 3-11 shows the scale error over the length of the driver motion (250 millimeters).

A very strange and interesting phenomenon is that when the output cable is connected to the left hand side of the coupler, the scale error has a positive slope and when it is connected to the right hand side, the scale error has a much larger negative slope. Combinations of these two, when connected to the center, all appear about the same. However, the fact that the slope passes through zero when picking off the coupler at a single point from the right hand side to the left hand side indicates that there probably is some point on the coupler where the output could be connected at which the scale error should be zero.

In figure 3-10 it should be noted that the balance error varies insignificantly as a function of coupler connection. This indicates that, assuming the proper point on the coupler were located, it would not in any significant way affect the balance accuracy within the pole pair.

Figures 3-12 and 3-13 show the accuracy of the Phasolver pattern with the output taken from the driver. The error within the pole pair is somewhat larger on this

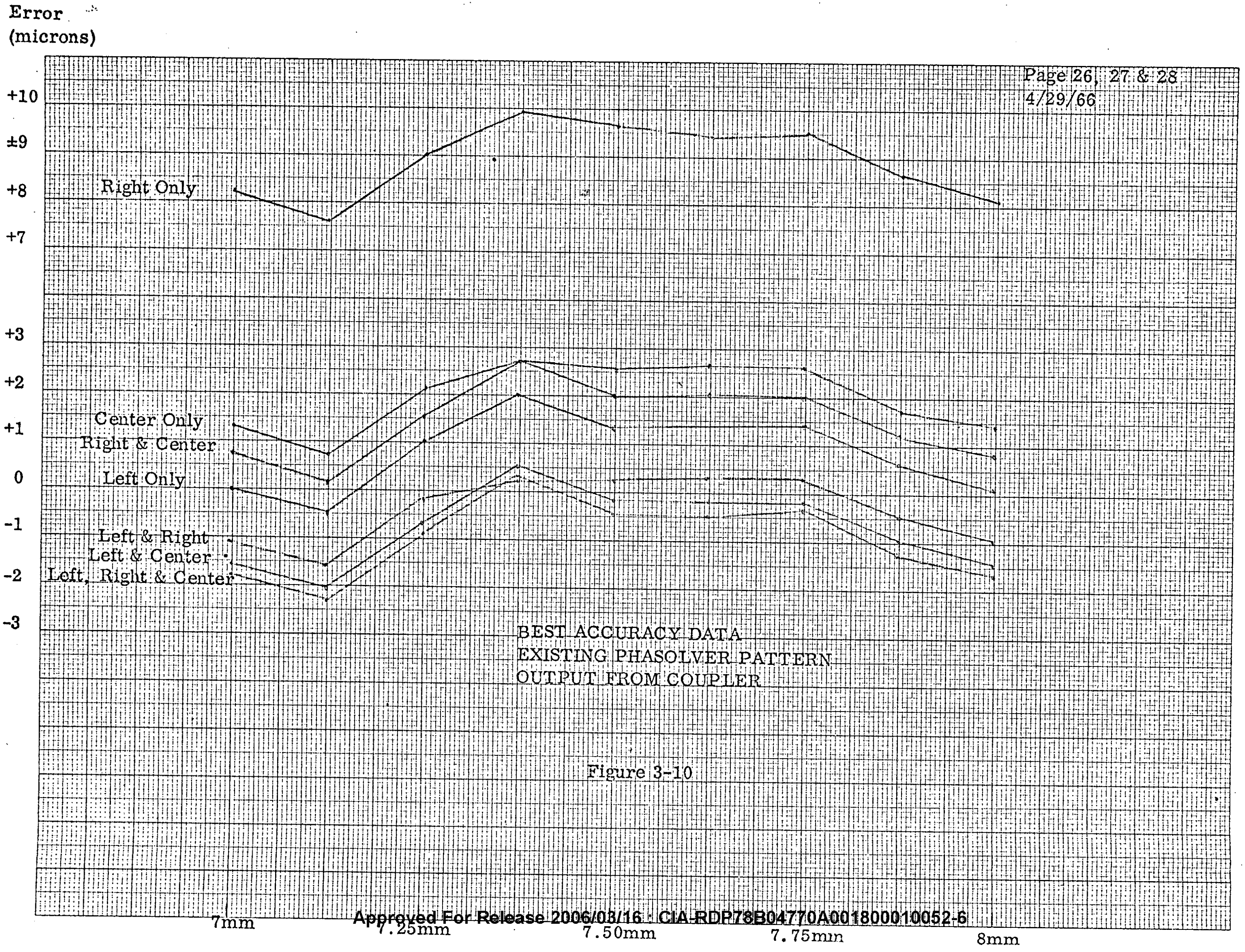

Error
(microns)
Page 26, 27 & 28
4/29/66
+10
±9
+8
+7
+3
+2
+1
0
-1
-2
-3
Right Only
Center Only
Right & Center
Left Only
Left & Right
Left & Center
Left, Right & Center
BEST ACCURACY DATA
EXISTING PHASOLVER PATTERN
OUTPUT FROM COUPLER
7mm
7.25mm
7.50mm
7.75mm
8mm

Figure 3-10

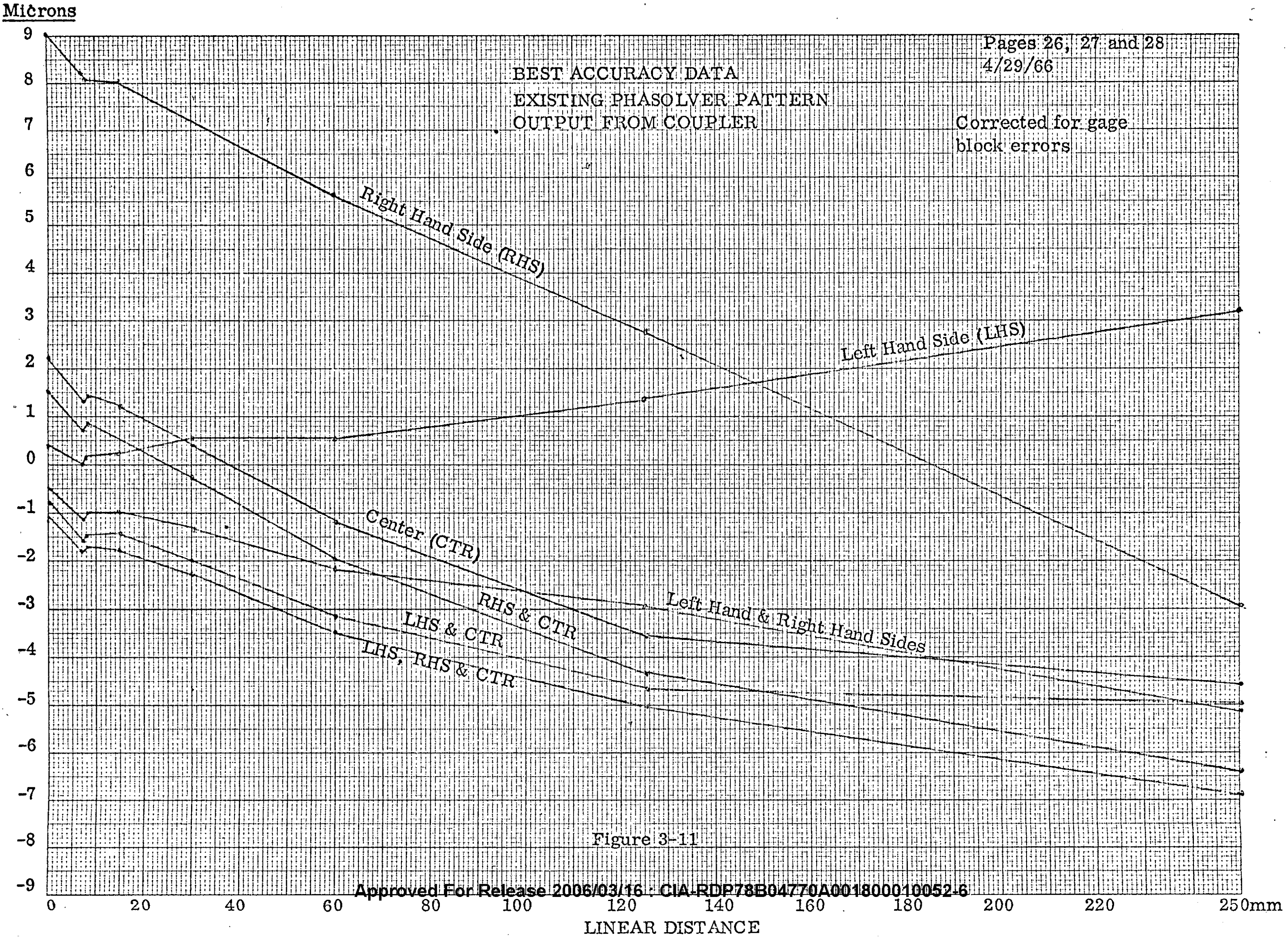
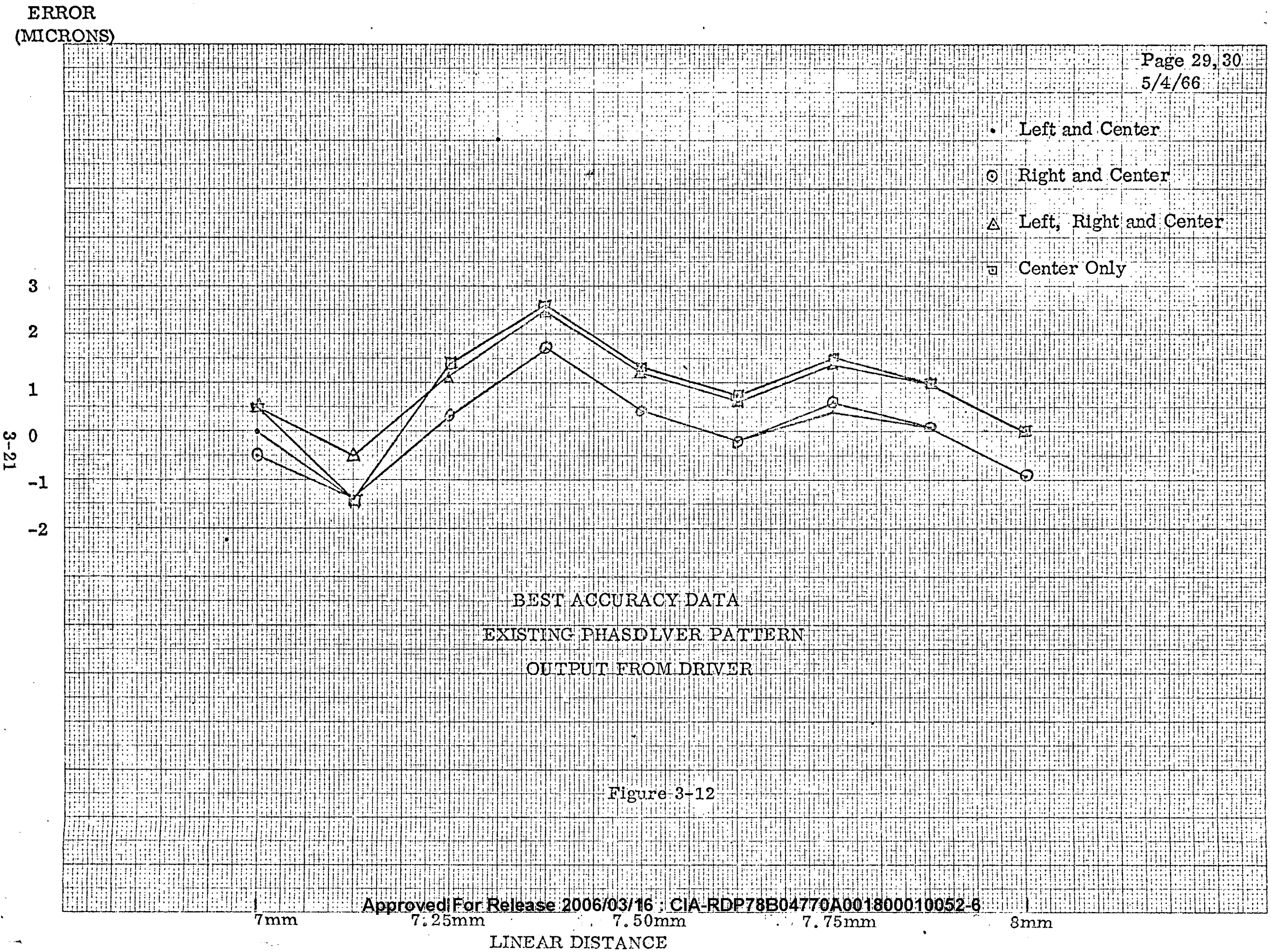

Microns
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
BEST ACCURACY DATA
EXISTING PHASOLVER PATTERN
OUTPUT FROM COUPLER
Pages 26, 27 and 28
4/29/66
Corrected for gage
block errors
Right Hand Side (RHS)
Left Hand Side (LHS)
Center (CTR)
RHS & CTR
Left Hand & Right Hand Sides
LHS & CTR
LHS, RHS & CTR
0
20
40
60
80
100
120
140
160
180
200
220
250mm
LINEAR DISTANCE

Figure 3-11



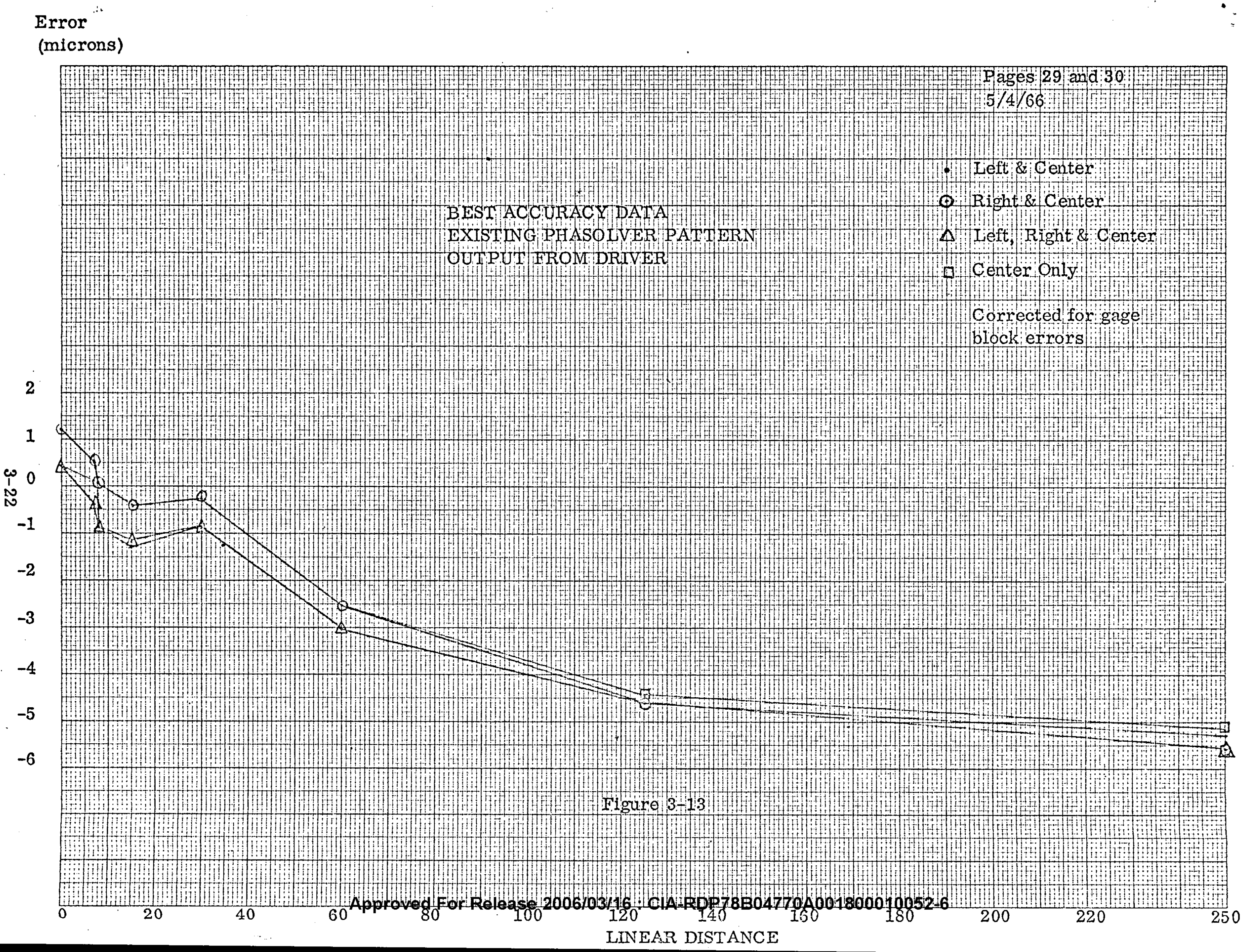
Page 29, 30
5/4/66

BEST ACCURACY DATA

EXISTING PHASOLVER PATTERN

OUTPUT FROM DRIVER

Figure 3-12



Pages 29 and 30
5/4/66

BEST ACCURACY DATA
EXISTING PHASOLVER PATTERN
OUTPUT FROM DRIVER

Corrected for gage block errors

Figure 3-13

graph. The nature of this error indicates that the error could probably not be eliminated by rebalancing. The error has a value of ± 1.5 microns.

Figure 3-13 shows the scale error of this pattern with the output taken from the driver. This output signal was routed to the driver in the following manner:

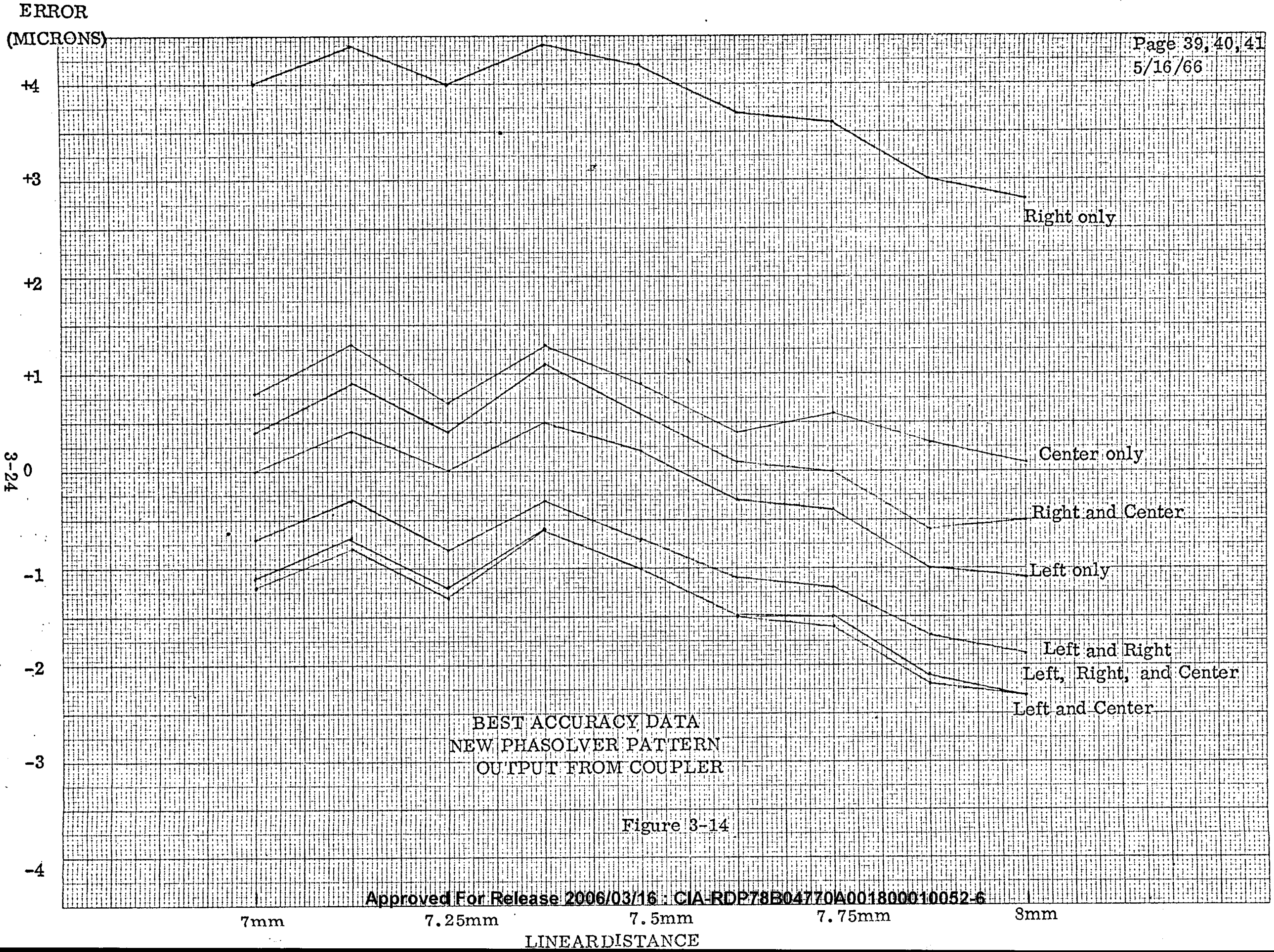
The coupler pattern on the stationary plate was connected to the large coupling area in the center of the coupler plate between the two coupler patterns. A conductive strip of silver paint made a connection from the center of the coupler to the coupling area and wires were connected to the end of the coupler pattern and the ends of the coupling area on the coupler plate. These wires went to switches so that as in the previous graph we would be able to switch connections between the coupler and the coupling area on the coupler to obtain all possible combinations. Unfortunately, it was not possible to disconnect the center connection at will in this configuration as it was in the previous data when the signal was taken from the coupler.

The output signal from the coupler which is connected to the coupling area is capacitively coupled to the coupling area on the driver plate from which it is connected to the electronics. The area of the coupling area is considerably larger than the area of the pattern and therefore presents a significantly lower impedance to the signal than the driver pattern itself.

The data shows two very interesting items. (1) All four curves are very similar to one another in value. The differences between the curves, regardless of coupler connections, are within 1 micron of each other, worst case. (2) The curves are nonlinear. The scale error from 0 to 125 millimeters is considerably more than the scale error from 125 millimeters to 250 millimeters. The error from 0 to 125 millimeters is approximately 5.5 microns while the error from 125 millimeters to 250 millimeters is less than 1 micron.

3.4.2 New Phasolver Pattern

The new Phasolver pattern was phase balanced in the same manner that the existing Phasolver pattern was balanced. Figure 3-14 shows the interpole accuracy data with the output signal taken from the coupler. This shows an error within the pole pair of approximately 1 1/4 microns; of which 3/4 micron appears to be the result of non-closure in the pole pair.



BEST ACCURACY DATA
NEW PHASOLVER PATTERN
OUTPUT FROM COUPLER

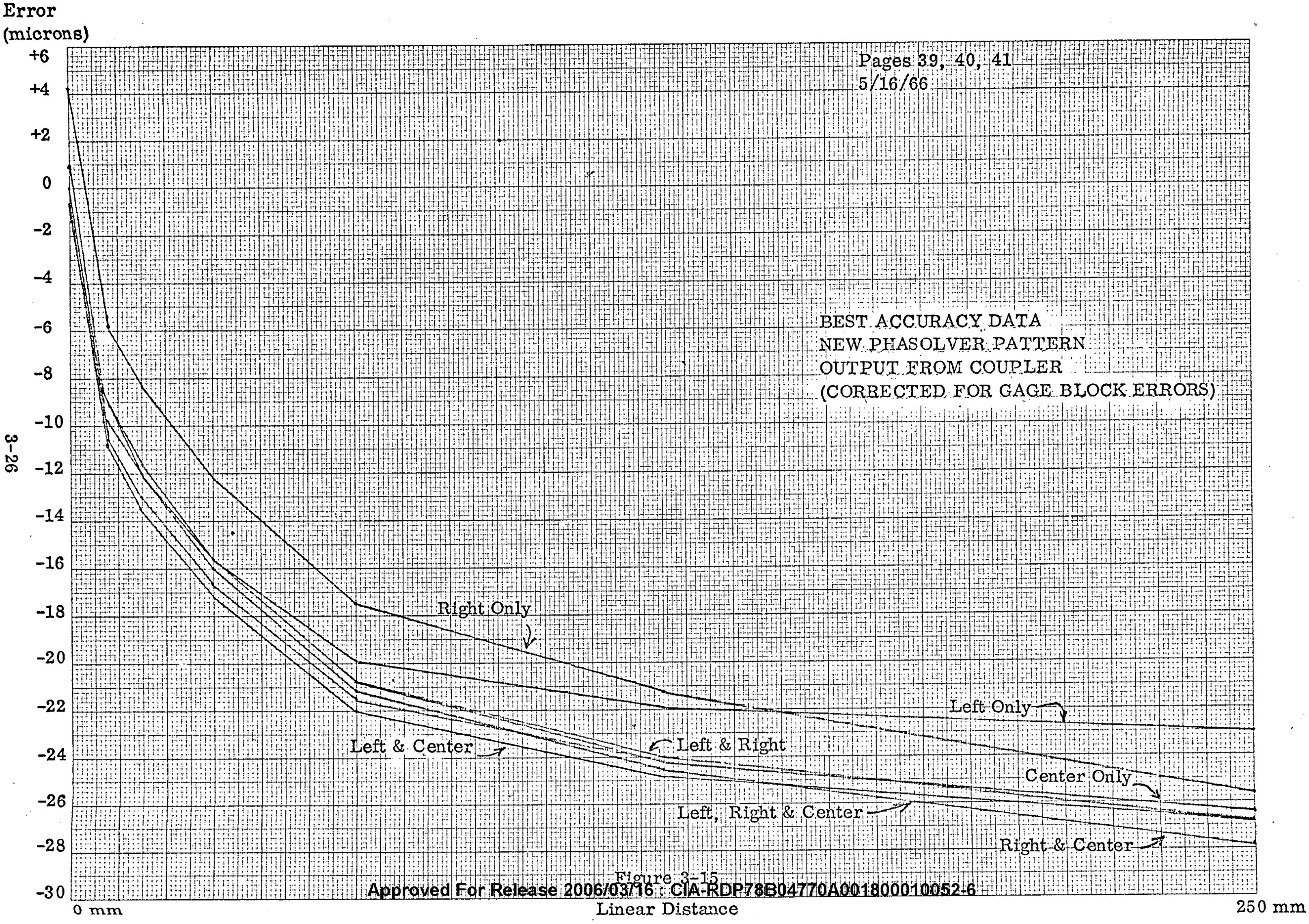
Figure 3-14

Figure 3-15 shows the scale error of this pattern over the full length of movement. The slope of the scale error around 7 millimeters where the system was balanced is approximately 1 micron per millimeter. This explains the nonclosure of the above pole pair data. If the scale error could be eliminated, the accuracy within the pole pair would appear to be about 1/2 micron. This data shows a very interesting correlation with the previous scale error curves. The curve with the largest negative slope is a curve taken from the right hand side of the coupler. The curve with the least negative slope is the curve taken from the left hand side of the coupler. The remaining connection combinations all appear to have the same error with no significant differences.

The nonlinear characteristic of the scale error exhibited in this curve appears to be quite similar to the curve in figure 3-16. Figure 3-16 was taken with the right cable only on this pattern but with perfect drive signals. A comparison of the slopes in the two curves shows that the slopes between the points where both are measured in common are very close together. This indicates that the scale error is not a function of balance. This was already evident since the balance was not affected when the scale error was changed by moving the output coupler connection (figure 3-14).

Figures 3-17 and 3-18 show the best balanced accuracy data for the new Phasolver pattern with the output signal taken from the driver. Figure 3-17 shows the accuracy within the pole pair. This curve was taken at a time when the new Phasolver pattern appeared to be rapidly deteriorating. This balance could be significantly improved over what is shown here. However, before the pattern could be rebalanced, all work stopped on this pattern for a lack of repeatability. The data shown here is the best data that was obtained from the pattern. No estimate of the ultimate accuracy that can be obtained from this pattern configuration can be made from the available data. However, this data shows some very interesting properties. A comparison with the corresponding data on the existing Phasolver pattern shows the identical sensitivity to changing the connections on the coupler. The worst case magnitude of change is 1 micron on both patterns. Aside from this change, the shape of the patterns is untouched.

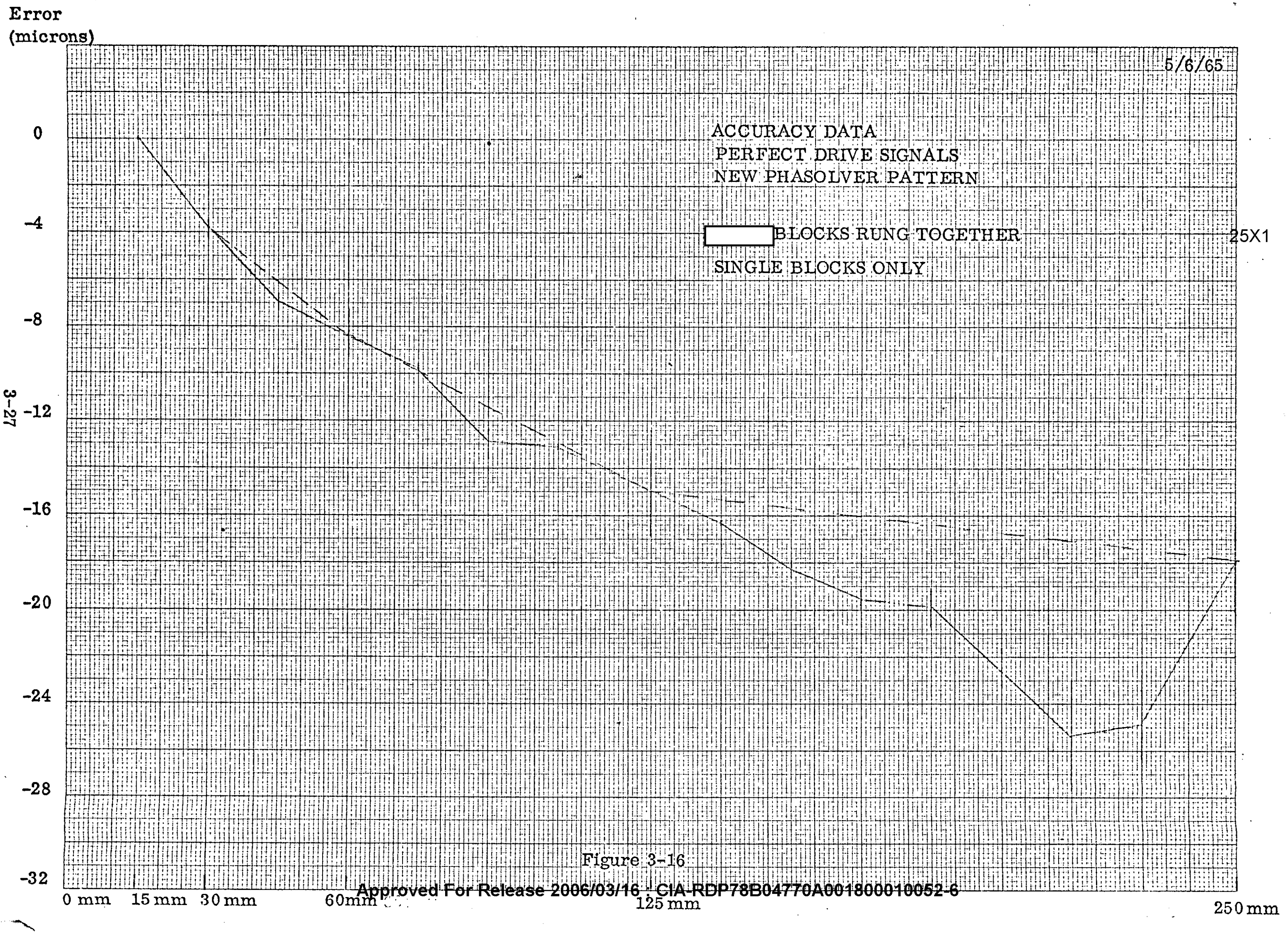
Figure 3-18 shows the scale error of this pattern. This curve shows the same characteristic as that of the corresponding curve on the existing Phasolver pattern. The scale error is unaffected by connections to the coupler. Again, in this pattern, the worst case sensitivity to changes of connections is 1 micron.



Pages 39, 40, 41
5/16/66

BEST ACCURACY DATA
NEW PHASOLVER PATTERN
OUTPUT FROM COUPLER
(CORRECTED FOR GAGE BLOCK ERRORS)

Figure 3-15



5/6/65

ACCURACY DATA
PERFECT DRIVE SIGNALS
NEW PHASOLVER PATTERN

[redacted] BLOCKS RUNG TOGETHER

SINGLE BLOCKS ONLY

25X1

Figure 3-16

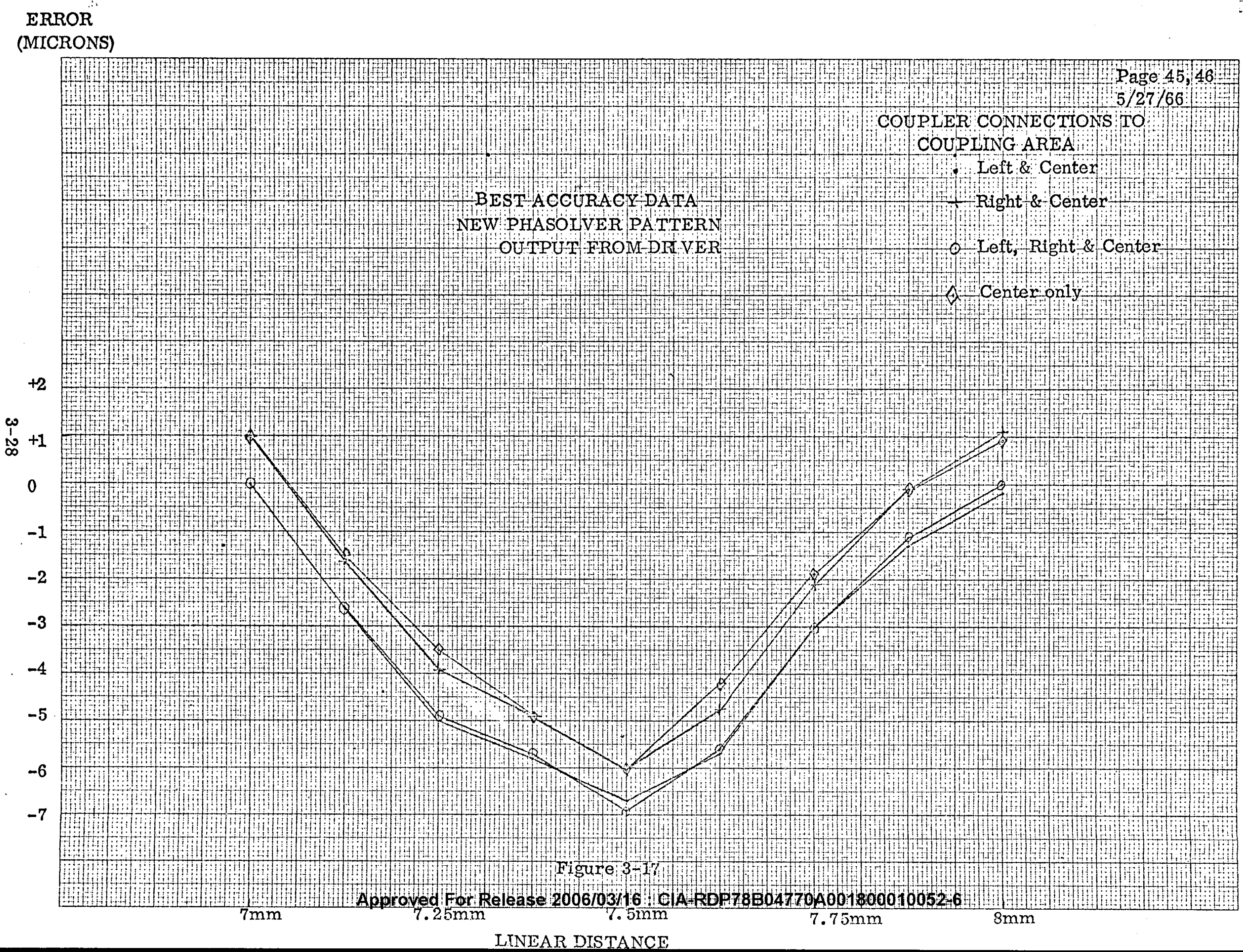

ERROR
(MICRONS)
Page 45, 46
5/27/66
COUPLER CONNECTIONS TO
COUPLING AREA
• Left & Center
+ Right & Center
○ Left, Right & Center
◇ Center only
BEST ACCURACY DATA
NEW PHASOLVER PATTERN
OUTPUT FROM DRIVER
+2
+1
0
-1
-2
-3
-4
-5
-6
-7
7mm
7.25mm
7.5mm
7.75mm
8mm
LINEAR DISTANCE

Figure 3-17

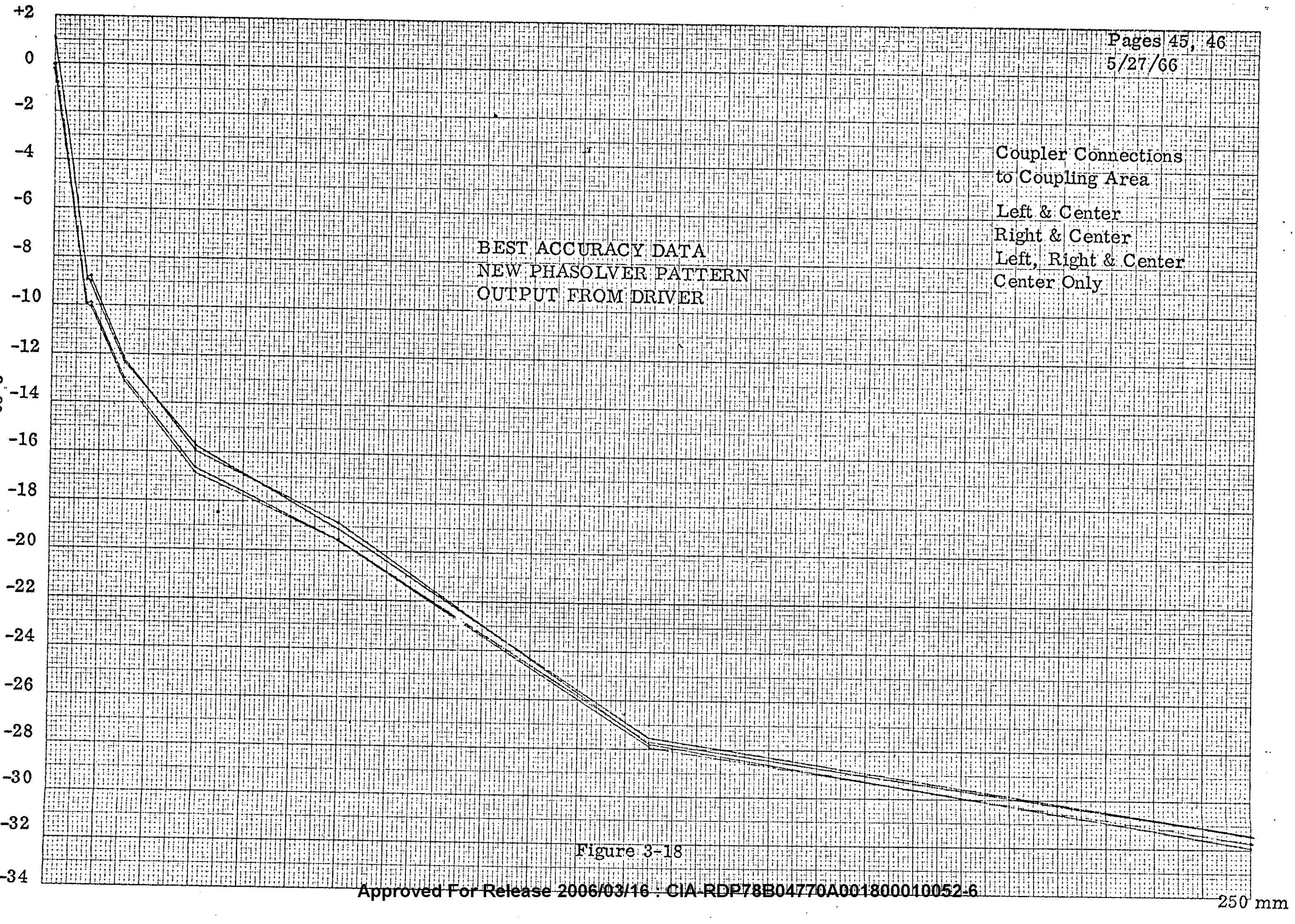

+2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
250 mm
Pages 45, 46
5/27/66
Coupler Connections
to Coupling Area
Left & Center
Right & Center
Left, Right & Center
Center Only
BEST ACCURACY DATA
NEW PHASOLVER PATTERN
OUTPUT FROM DRIVER

Figure 3-18

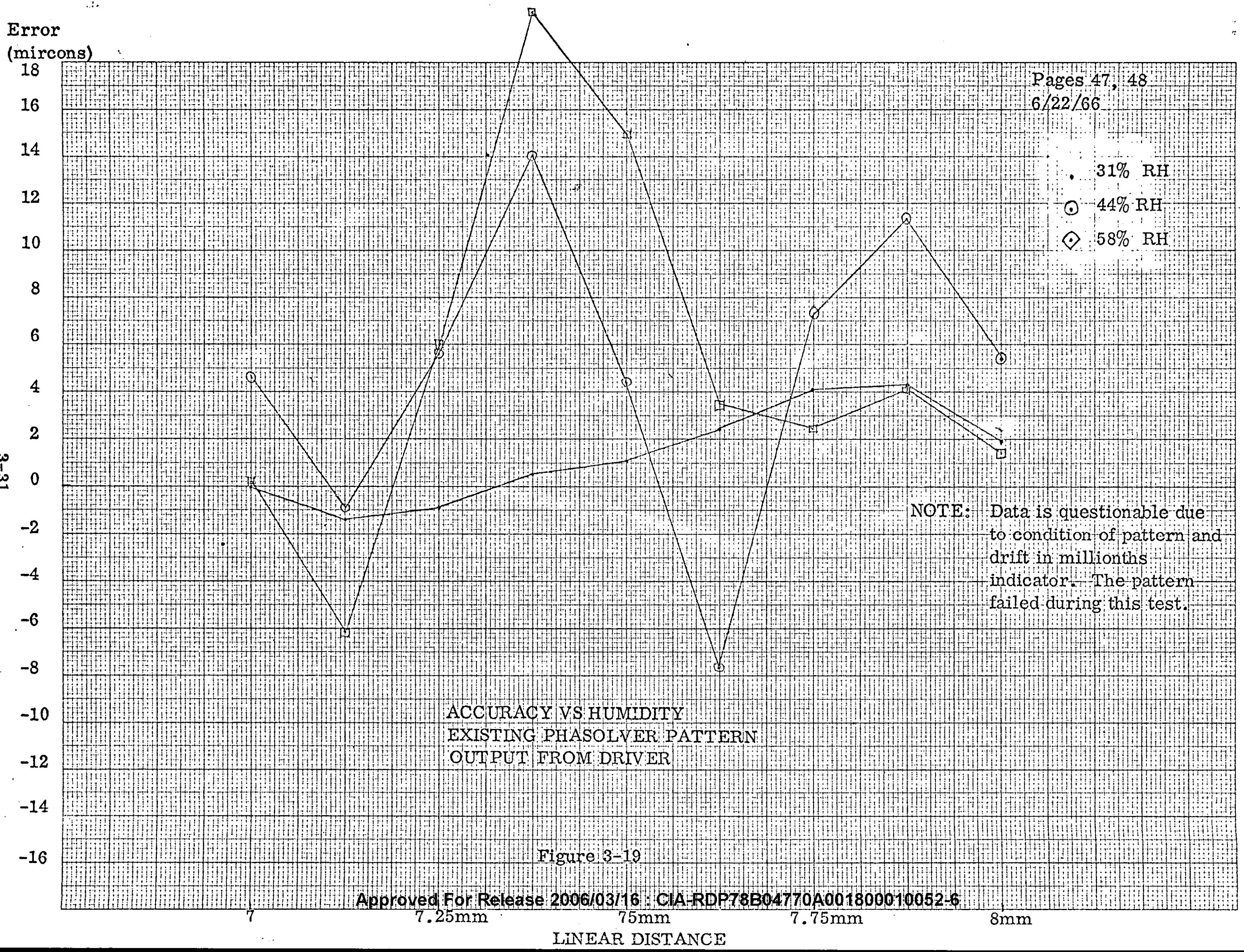
3.5 HUMIDITY TEST

The purpose of this test was to determine the sensitivity of the Phasolver to the relative humidity of the air in the vicinity of the Phasolver plates.

For the purposes of this test, the dust free chamber in which the test fixture was mounted was sealed as well as possible from the outside environment with mylar tape. Bottled dry nitrogen was fed into the chamber and also into an air washing bottle in which the nitrogen was bubbled through a water bath. The output of the washing bottle was fed into the chamber. By mixing the dry nitrogen and wet nitrogen coming from the washing bottle, it was possible to adjust the relative humidity of the air in the chamber without seriously disturbing the temperature. Although undoubtedly some cooling of the gas occurred when the nitrogen absorbed the water vapor from the water bath (as occurs in an evaporative cooler), no change was noted in the temperature of the air inside the chamber itself. Simple absorption type relative humidity indicators, which had previously been calibrated, were used to monitor the relative humidity.

Three test runs were made using the existing Phasolver pattern. The first run was made at 31 percent relative humidity. With 100 percent dry nitrogen, the humidity could not be brought down below 20 percent. Presumably moisture trapped in the materials inside the chamber, such as the cables and gaskets surrounding the test fixture, outgassed and maintained the moisture content at a relatively high level for a long period of time. The system was balanced roughly by an amplitude balance method at this relative humidity. The humidity was then raised slightly to 44 percent and allowed to stabilize for about 4 hours. A run was made and the humidity was then increased to the maximum relative humidity that could be obtained using only the washing bottle. The humidity stabilized from this technique at 58 percent relative humidity. In order to obtain a higher relative humidity we would have had to heat the water in the air washing bottle. This would have caused a temperature change in the chamber.

The data obtained in this test is shown in figures 3-19 and 3-20. Figure 3-19 shows the accuracy within the pole pair from 7 millimeters to 8 millimeters. Figure 3-20 shows the scale accuracy over the full length of linear motion. Figure 3-19 shows a considerable degradation in accuracy as a function of humidity. The accuracy goes from 5 microns peak-to-peak to 28 microns peak-to-peak as the relative humidity

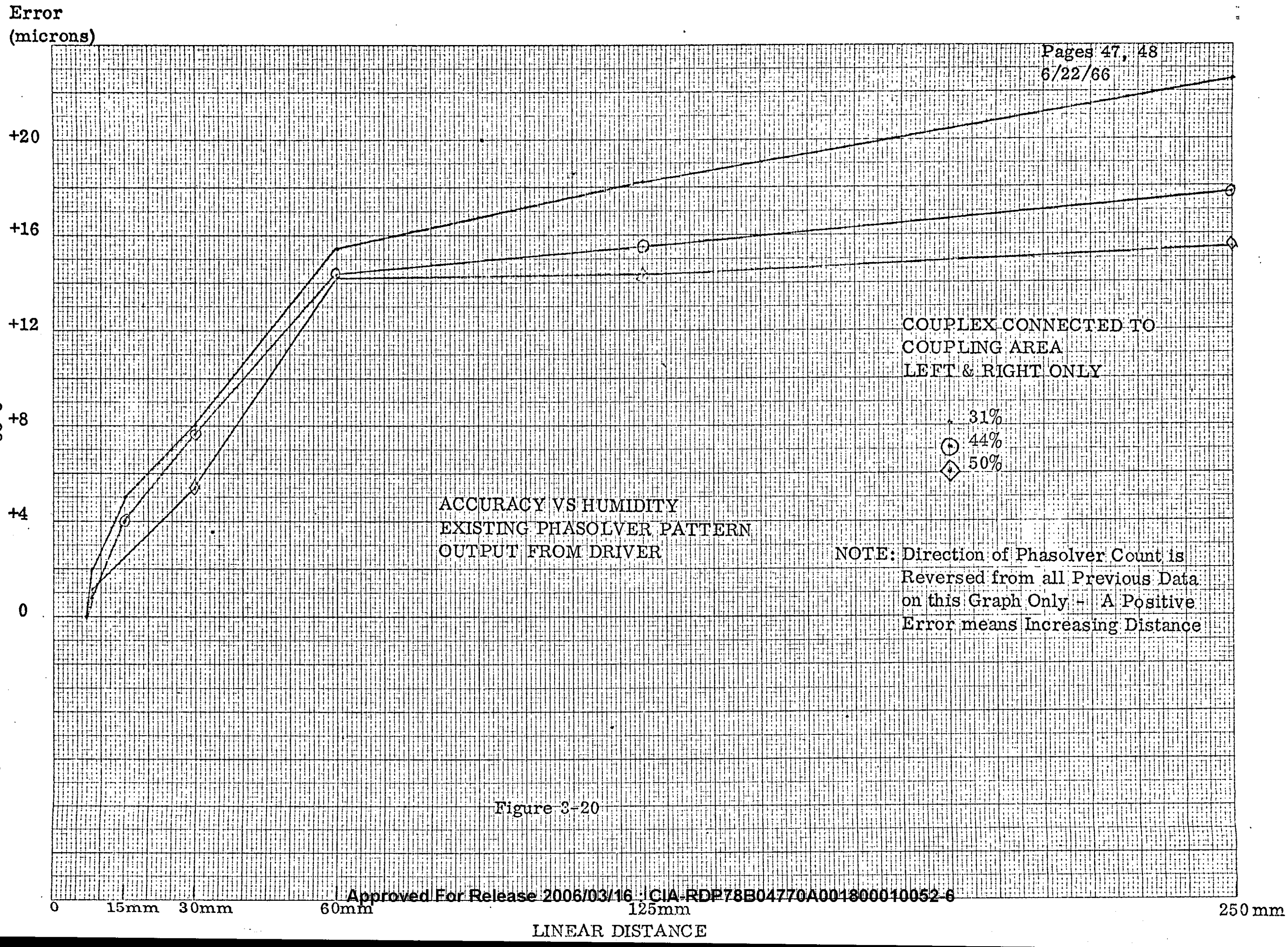


Pages 47, 48
6/22/66

NOTE: Data is questionable due to condition of pattern and drift in millionths indicator. The pattern failed during this test.

ACCURACY VS HUMIDITY
EXISTING PHASOLVER PATTERN
OUTPUT FROM DRIVER

Figure 3-19



ACCURACY VS HUMIDITY
EXISTING PHASOLVER PATTERN
OUTPUT FROM DRIVER

COUPLEX CONNECTED TO
COUPLING AREA
LEFT & RIGHT ONLY

NOTE: Direction of Phasolver Count is Reversed from all Previous Data on this Graph Only - A Positive Error means Increasing Distance

Figure 3-20

rises from 31 percent to 58 percent. The validity of this data is in question, however, since the pattern failed during the final repeat run at 30 percent relative humidity. The purpose of this run was to determine the validity of the test.

Figure 3-20 shows a significant bit of information. The 0 degree and 180 degree drive signals were interchanged on the existing pattern to change the direction of motion for increasing count. In other words, on all other tests, as the driver plate moved from left to right, the Phasolver count decreased. In this test, the Phasolver count increased as the driver plate moved from left to right. Figure 3-20 shows a scale error which has inverse properties of the scale error of all other graphs. The slope is very positive from 0 to 60 millimeters and while remaining positive, becomes much smaller as the motion approaches 250 millimeters. This eliminates the hypothesis that the scale error is electrical in nature, since any electrical error would behave the same regardless of the way the Phasolver was connected. As an example, any variable phase shift in the coupler circuit due to a variable resistance in the coupler pattern, as the driver moved over the pattern, would always cause a variable lag in the output signal. However, the fact that this error is reversed from the previous tests indicates that the scale error has indeed some other source.

3.6 COARSE CHANNEL TEST

The Linear Phasolver test fixture and the coarse channel encoder were installed together. A cable loop drive was used from the driver plate to the pulley which turns the coarse encoder. The encoder is geared up by a 4 to 1 gear ratio. This ratio in combination with the size of the pulley wheel controls the encoder scale. This was set at 10 counts per millimeter as was explained earlier in the text.

Difficulties were encountered in obtaining repeatable operation because of slippages of the drive cable over the coarse encoder pulley. The torque of the coarse encoder when multiplied by the 4 to 1 gear ratio is sufficient to cause some slippage in the drive cable over the pulley. Operation of the coarse channel over the full length was obtained, however, and demonstrated that the coarse channel did indeed function properly. In order to eliminate the slippage of the drive cables, it would have been necessary to replace the drive pulley with a special spiral groove pulley. This was not done because of schedule and funding limitations.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

From the data obtained in this program and included in this report, it is clear that Linear Phasolver has fulfilled the basic requirements for which it was intended. The resolution, repeatability and accuracy of the unit either exceeds or very closely approaches the design goals. The scale error over the length of the pattern is, unfortunately, significant. However, it is repeatable and can easily be eliminated digitally elsewhere in the system, if necessary. The linear instability which has caused a great deal of difficulty is believed to be caused by something in the system other than the Phasolver. The fact that the Phasolver reading remained constant while the millionths indicator, which was used as a reference point, varied, indicates that some other portion of the fixture was changing. This could have been an uncontrolled movement of any item in series with the indicator and Phasolver.

The humidity data indicates a more serious problem area. The Phasolver will require a supply of dry air in the environment of the Phasolver plates to maintain any stability. This is not a difficult requirement to cope with.

This system has shown such promise that the development of a working model should be continued. It is recommended that the test fixture be redesigned to allow overhead ways to support the gage blocks, eliminating any interference with the patterns. Also, it is advisable to provide a positive guide to secure the driver against the guide block during travel. This would allow the measurement takeoff to be placed in the center of the driver on top. Any expansion of the driver would then be symmetrical fore and aft of a theoretical center and would cancel out any errors.

Redesign of the driver would allow direct contact to the driver patterns similar to the method used on the existing Phasolver. The use of shielded cables would eliminate coupling of any energy from the drive lines directly to the coupling areas and prevent uncontrolled coupling of the drive signals to the output. The driver patterns could be put on the plates with the techniques used in the fabrication of the existing Phasolvers since there is now a photo-master. This would result in better patterns since [redacted] has considerable in-house technical knowledge on this process.

S AT

It is also suggested that more gage blocks be used, encompassing all of the measurements to be made.

With these modifications, it is believed that the source of some of the problems and their solutions could be found and that the testing program could be pursued to a satisfactory conclusion.

APPENDIX A

LINEAR PHASOLVER DEVELOPMENT PROGRAM

PHASE II SYSTEM TEST PROCEDURE

General Test Conditions and Special Instructions

1. Ambient Temperature: 68°F ±1°F
2. Ambient Relative Humidity: Within the range 30 - 50 percent, but controlled to ±5 percent at set point.
3. The system shall be soaked at constant temperature for several hours prior to any tests.
4. The number of heat sources in the room should be kept to a minimum:
   a. One test operator (two operators during balance).
   b. One electronics subsystem including the 100 mc counter and crystal oscillator.
5. Precautions should be taken to prevent hands or other parts of body from touching the fixture during the test period to minimize thermal changes.
6. Gloves or tongs are to be used when handling gage blocks. Do not touch blocks with bare hands.

Pattern Identification (Figure 2-3)

1. The existing Phasolver pattern hereafter will be referred to as Pattern I.
2. Areas 9 through 17 and Areas 18 through 26 of the new Phasolver pattern will be referred to as Patterns IIA and IIB respectively.
3. The new Phasolver pattern, which is IIA and IIB connected in parallel, will be referred to as Pattern III.

TEST 1 Co/Cv Determination

1.1 Test Conditions

1.1.1 Gap + 0.0015 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

1.1.2 Set up plates for minimum skew. Record all pertinent set-up dimensions.

1.2 Measure Co, Cv, and compute Co/Cv for Patterns I, IIA, IIB and III with the outputs taken from the coupler patterns.

1.3 Measure Co, Cv, and compute Co/Cv for Patterns I, IIA, IIB and III with the outputs taken from the driver patterns.

1.4 Repeat 1.2 for 0.004, 0.003 and 0.002 inch nominal gap.

1.5 Review results.

1.6 Set Gap at best compromise of Co/Cv ratio and mechanical clearance

TEST 2 Accuracy, Resolution, Test Repeatability

2.1 Test Conditions and Procedures

2.1.1 Gap = 0.0025 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

2.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

2.1.3 Adjust preamplifier gain for 3 volts peak-to-peak signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to the start of any test.

2.1.4 Counter readings are to be recorded as the range of readings seen for each plate position: Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

2.1.5 Output is to be taken from the coupler patterns.

2.2 Accuracy with Equal Amplitudes and Phase Quadrature Drive Signals - Pattern I.

2.2.1 Adjust the amplitudes and phases of the drive signals such that the amplitudes are equal within ±0.0001 vrms and the phases are in quadrature within ±10 nanosecs.

2.2.2 Perform an accuracy run starting at 0 mm. The actual system output shall be recorded for the following positions: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250 mm. Compute the system error (correct system output minus actual system output).

2.2.3 Repeat 2.2.2 once. This is to be accomplished directly upon completion of 2.2.2 without interruption.

2.2.4 Review the results of 2.2.2 and 2.2.3.

2.3 Accuracy with Equal Amplitudes and Phase Quadrature Drive Signals - Patterns IIA, IIB, and III.

2.3.1 Repeat 2.2 for each of the above patterns.

2.4 Balance, Accuracy, and Test Repeatability - Pattern I.

2.4.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

2.4.2 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters:

0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

2.4.3 Repeat 2.4.2 once. This is to be accomplished directly upon completion of 2.4.2 without interruption.

2.4.4 Review the results of 2.4.2 and 2.4.3.

2.5 Balance, Accuracy, and Test Repeatability - Patterns IIA, IIB and III.

2.5.1 Repeat 2.4 for each of the above patterns.

TEST 3 Pattern Separation

3.1 Test Conditions

3.1.1 Gap = 0.0025 inch nominal. Record measured value (height of feet with respect to surface of driver plate.

3.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

3.1.3 Adjust preamplifier gain for predetermined signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to start of any test.

3.1.4 Counter readings are to be recorded as the range of readings seen for each plate position. Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

3.1.5 Output is to be taken from the coupler patterns.

3.1.6 Energize alternate sections of Patterns IIA and IIB to represent a Phasolver pattern with increased spacing of individual pattern segments.

3.2 Accuracy with Equal Amplitudes and Phase Quadrature Drive Signals.

3.2.1 Adjust the amplitudes and phases of the drive signals such that the amplitudes are equal within ±0.0001 vrms and the phases are in quadrature within ±10 nanosecs.

3.2.2 Perform an accuracy run. The actual system output shall be recorded for the following positions: 0, 7 mm, 7.125, 7.250, 7.375 7.500, 7,625, 7.750, 7.875, 8, 15, 30, 60, 125, 250 mm. Compute the system error; correct system output - actual system output.

3.2.3 Repeat 3.2.2 once. This is to be accomplished directly upon completion of 3.2.2 without interruption.

3.2.4 Review the results of 3.2.2 and 3.2.3.

3.3 Balance, Accuracy, and Test Repeatability

3.3.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

3.3.2 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625 7.750, 7.875, 8, 15, 30, 60, 125, 250.

3.3.3 Repeat 3.3.2 once. This is to be accomplished directly upon completion of 3.3.2 without interruption.

3.3.4 Review the results of 3.3.2 and 3.3.3

TEST 4 Driver Coupled Output

4.1 Test Conditions

4.1.1 Gap = 0.0025 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

4.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

4.1.3 Adjust preamplifier gain for predetermined signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to start of any test.

4.1.4 Counter readings are to be recorded as the range of readings seen for each plate position. Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

4.1.5 Output is to be taken from wide output band of the driver plate. The coupler pattern should be connected to the wide band on the coupler plate.

4.1.6 Use the pattern which produced the best accuracy results in 2.2, 2.3, 2.4 and 2.5.

4.2 Accuracy with Equal Amplitudes and Phase Quadrature Drive Signals.

4.2.1 Adjust the amplitudes and phases of the drive signals such that the amplitudes are equal within ±0.0001 vrms and the phases are in quadrature within ± 10 nanosecs.

4.2.2 Perform an accuracy run over a pole pair span (one mm travel) starting at 7 mm. The actual system output shall be recorded for the following positions: 0, 7 mm, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8 mm. Compute the system error; correct system output-actual system output.

4.2.3 Repeat 4.2.2 once. This is to be accomplished directly upon completion of 4.2.2 and 4.2.3.

4.3 Balance, Accuracy, and Test Repeatability

4.3.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

4.3.2 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

4.3.3 Repeat 4.3.2 once. This is to be accomplished directly upon completion of 4.3.2 without interruption.

4.3.4 Review the results of 4.3.2 and 4.3.3.

TEST 5 Skew

5.1 Test Conditions

5.1.1 Gap = 0.0025 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

5.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

5.1.3 Adjust preamplifier gain for predetermined signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to start of any test.

5.1.4 Counter readings are to be recorded as the range of readings seen for each plate position. Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

5.1.5 Output is to be taken from the coupler patterns.

5.2 Pattern I - Balance, Accuracy, and Test Repeatability.

5.2.1 Perform a phase balance starting at 7 mm, Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

5.2.2 Perform an accuracy run for 280 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

5.2.3 Introduce 0.0002 inch/inch of driver skew with respect to the coupler pattern.

[illegible]

[illegible]

5.2.4 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

5.2.5 Rephase balance for minimum error within a pole pair span starting at 7 mm.

5.2.6 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

5.2.7 Review results.

5.2.8 Introduce a second value of skew selected on the basis of results obtained in 5.2.1 through 5.2.7.

5.2.9 Repeat 5.2.1 through 5.2.7.

5.3 Pattern III - Repeat 5.2 for Pattern III.

TEST 6 Tilt

6.1 Test Conditions

6.1.1 Gap = 0.0035 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

6.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

6.1.3 Adjust reamplifier gain for predetermined signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to start of any test.

6.1.4 Counter readings are to be recorded as the range of readings seen for each plate position. Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

6.1.5 Output is to be taken from the coupler patterns.

6.2 Pattern I - Tilt Axis A (Defined in 6.2.2)

6.2.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

6.2.2 Introduce 10 arc seconds of tilt with respect to rotation about an axis which is perpendicular to an axis along the line of travel.

6.2.3 Measure resultant error within a pole pair span starting at 7 mm.

6.2.4 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

6.2.5 Rephase balance for minimum error within a pole pair span starting at 7 mm.

6.2.6 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

6.2.7 Review results.

6.2.8 Return to zero tilt.

6.2.9 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

6.2.10 Introduce a second value of tilt selected on the basis of the results obtained in 6.2.3 through 6.2.7.

6.3 Pattern I - Tilt B (Defined in 6.3.2)

6.3.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

6.3.2 Introduce 30 arc seconds of tilt with respect to rotation about an axis along the line of travel.

6.3.3 Measure resultant error within a pole pair span starting at 7 mm.

6.3.4 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Compute the normalized system error (zero system error at 265 mm). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

6.3.5 Rephase balance for minimum error within a pole pair span starting at 7 mm.

6.3.6 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

6.3.7 Review results.

6.3.8 Return to zero tilt.

6.3.9 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (9 positions).

6.3.10 Introduce a second value of tilt selected on the basis of the results obtained in 6.3.3 through 6.3.7.

6.3.11 Repeat 6.3.3 through 6.3.8.

6.4 Patterns IIA or IIB, III and Separated Pattern

6.4.1 Repeat 6.2 and 6.3 for the above patterns.

TEST 7 Gap

7.1 Test Conditions

7.1.1 Gap = 0.0025 inch nominal. Record measured value (height of feet with respect to surface of driver plate).

7.1.2 Set up plates for minimum skew. Record all pertinent setup dimensions.

7.1.3 Adjust preamplifier gain for predetermined signal amplitude at ZCD input. This value is to be used for all tests and is to be checked prior to start of any test.

7.1.4 Counter readings are to be recorded as the range of readings seen for each plate position. Example:

Position (CM)	Counter Reading (Microseconds)
10.000	100.00 - 100.03

7.1.5 Output is to be taken from the coupler patterns.

7.2 Pattern I

7.2.1 Perform a phase balance starting at 7 mm. Record final balance readings. Compute system error. Use 8 intervals within a pole pair (positions).

7.2.2 Set gap at 0.0035 inch. During the time interval that the gap change is made, the electronics shall remain on, with standard test conditions maintained. The amplitude of the drive signals shall be measured prior to removal and after reinstallation of the driver plate.

7.2.3 Measure resultant error within a pole pair span starting at 7 mm.

[illegible]

7.2.4 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacements in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7,625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

7.2.5 Rephase balance for minimum error within a pole pair span starting at 7 mm.

7.2.6 Perform an accuracy run for 250 mm travel. Record actual system output; compute the system error (correct system output minus actual system output). Use the following displacement in millimeters: 0, 7, 7.125, 7.250, 7.375, 7.500, 7.625, 7.750, 7.875, 8, 15, 30, 60, 125, 250.

7.2.7 Review results

7.3 Measure Co, Cv, and compute Co/Cv for Patterns I, IIA, IIB and III with the output taken from the coupler pattern.

7.4 Measure Co, Cv, and compute Co/Cv for Patterns I, IIA, IIB and III with the output taken from the driver pattern.

7.5 Patterns IIA or IIB

7.5.1 Repeat 7.1 and 7.2 for Patterns IIA or IIB.

7.6 Pattern III

7.6.1 Repeat 7.1 and 7.2 for Pattern III.

7.7 Separated Pattern

7.7.1 Repeat 7.1 and 7.2 for separated pattern used in Test 3.

7.8 Repeat 7.1 through 7.7 using a gap setting of 0.007 inch in 7.2.3.

THIRTY-THIRD MONTHLY PROGRESS REPORT

MODEL 933 PHASOLVER SYSTEM

10 MAY 1966

I. SUMMARY

1.1 The system accuracy testing is continuing. Since the test fixture was placed in a "Sterishield" chamber we have had little further pattern damage. The accuracy tests on the 915B-1 pattern (normal Phasolver pattern) have been completed.

The data obtained to date is both interesting and encouraging. The system exhibits a scale error which is sensitive to the pickoff point on the coupler pattern. This scale error varies from -8.5 microns to +2 microns in 250 millimeters as the pickoff point on the coupler is moved from one end to the other. See Figure I. This error is independent of the balance condition. If the coupler signal is capacitively coupled to the driver disk, the scale error is independent of the pickoff point on the coupler. See Figure II.

The error within the pole pair with perfect quadrature drive signals is approximately 32 microns peak to peak. With balancing, the error has been reduced to 2.3 microns peak to peak. See Figure III. The repeatability of this measurement is less than 0.4 microns peak to peak.

Measurements on the new (bow-tie) pattern have begun. The pattern has deteriorated sufficiently [illegible] the output does not shift phase through 360 degrees with perfect quadrature drive signals. However, with balancing the output can be made to shift phase linearly. No quantitative figures on accuracy are available yet.

1.2 The coarse channel fixtures have been fabricated and are awaiting a convenient time to incorporate them into the test fixture.

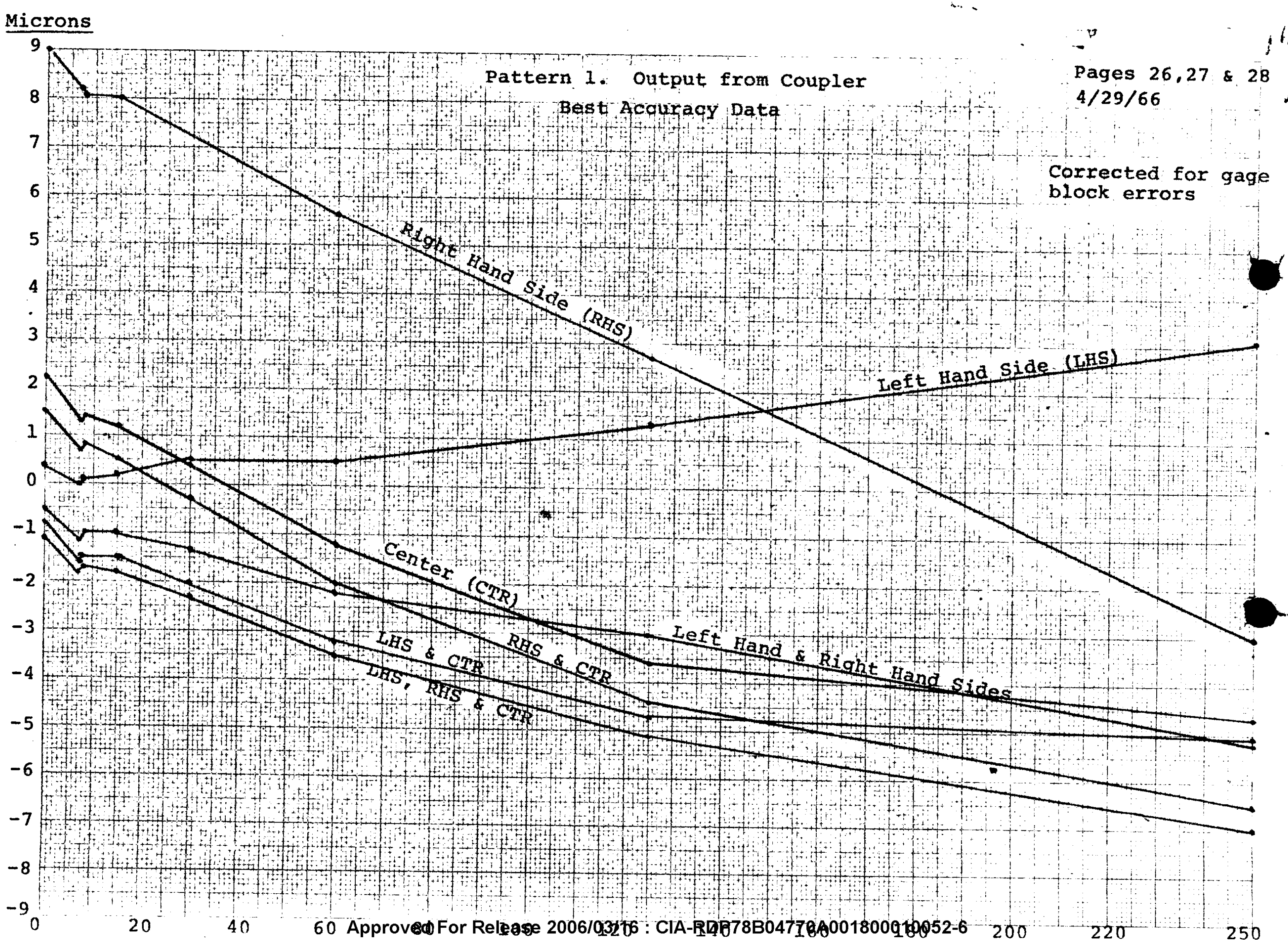
2. WORK PLANNED FOR NEXT REPORT PERIOD

2.1 Complete the accuracy testing.

2.2 Incorporate the coarse channel into the test fixture.

2.3 Complete the humidity testing.

2.4 Write the final report.



Pattern 1. Output from Coupler
Best Accuracy Data

Pages 26,27 & 28
4/29/66

Corrected for gage block errors

FIGURE I

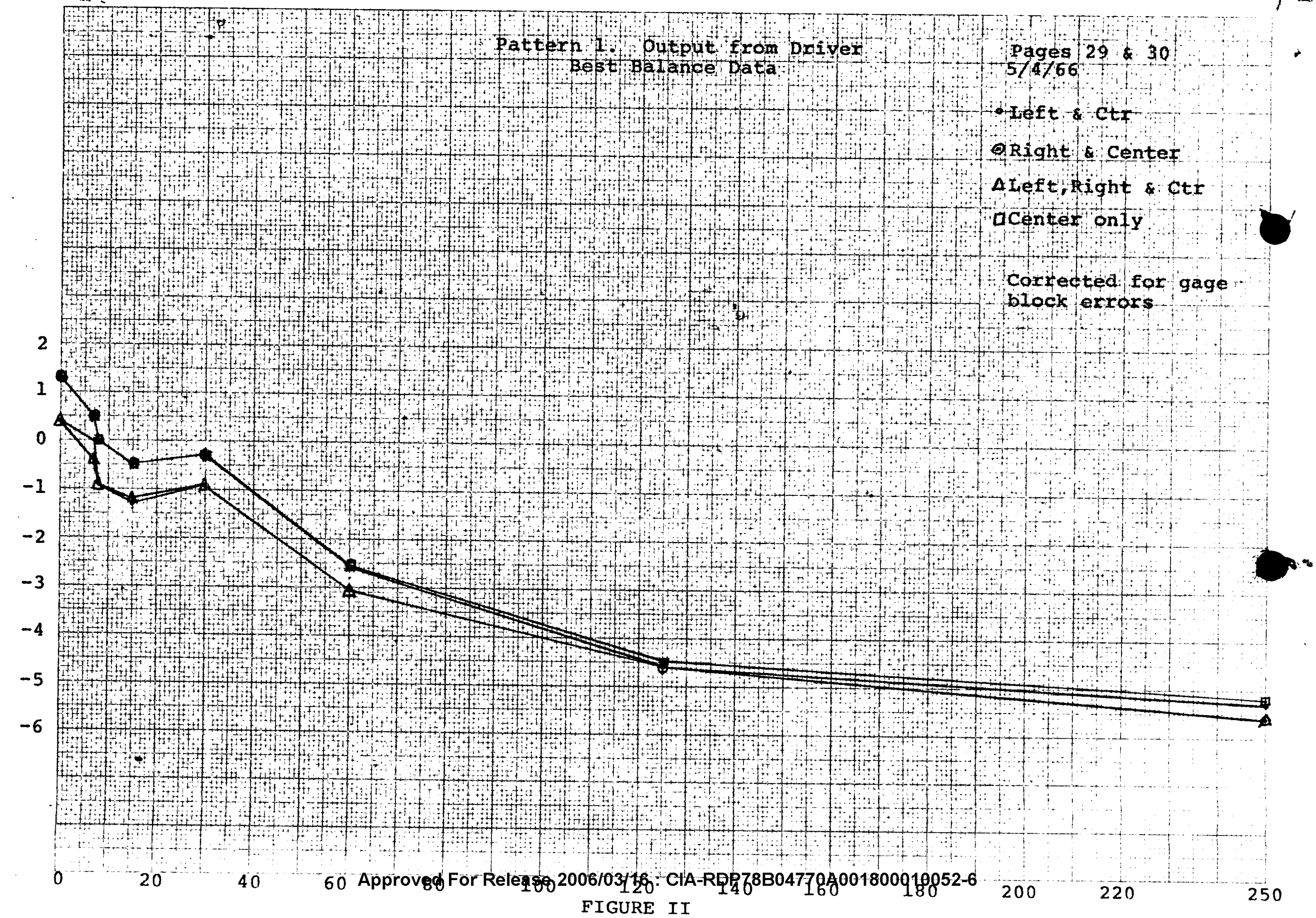
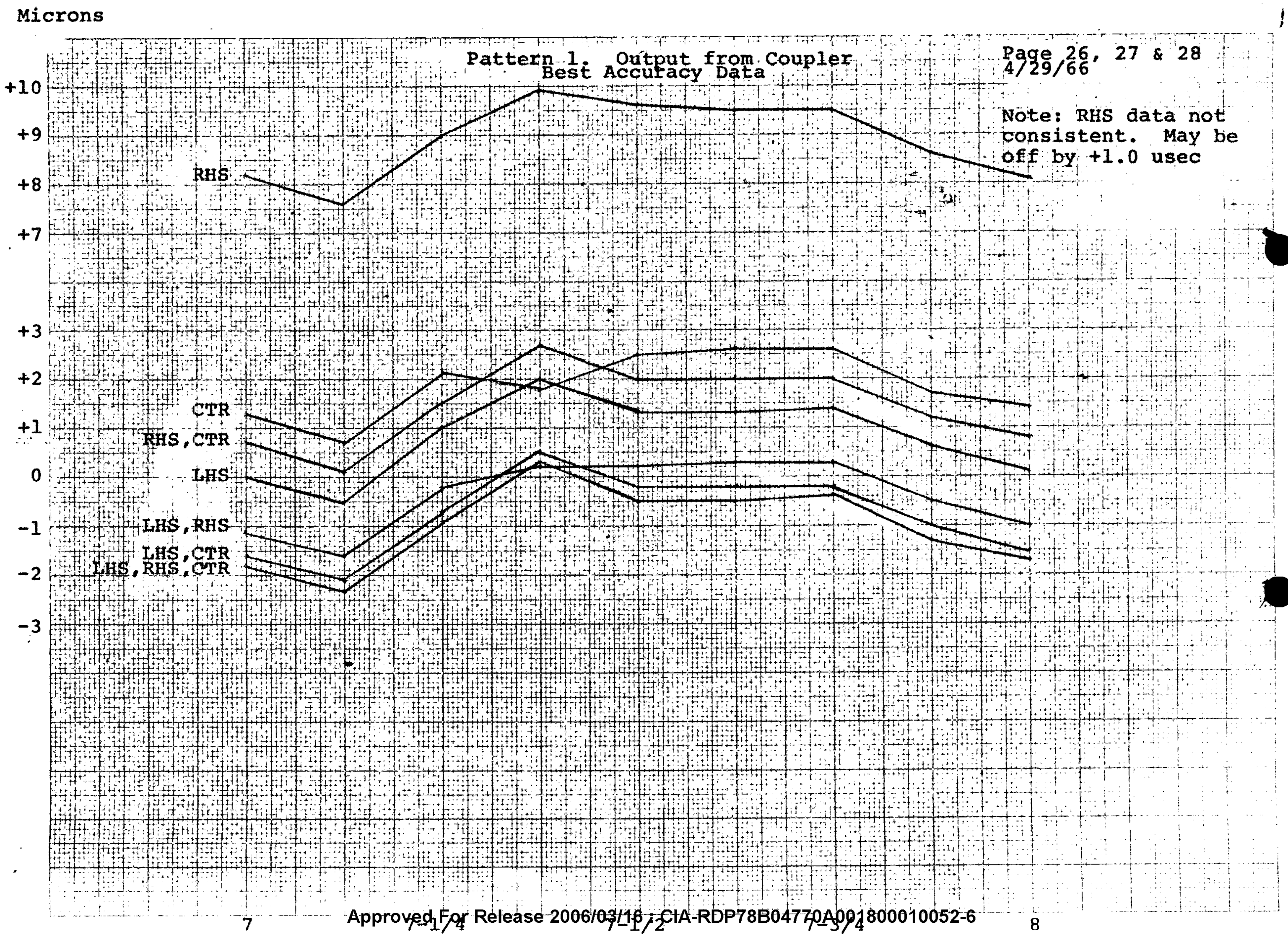

Pattern 1. Output from Driver
Best Balance Data
Pages 29 & 30
5/4/66
● Left & Ctr
⊙ Right & Center
△ Left,Right & Ctr
□ Center only
Corrected for gage block errors
2
1
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80
100
120
140
160
180
200
220
250

FIGURE II



Pattern 1. Output from Coupler
Best Accuracy Data

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Note: RHS data not consistent. May be off by +1.0 usec

FIGURE III