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INDUSTRIAL PREPAREDNESS STUDY ON
TIGHTER TOLERANCE CR-(XM-22)/U
CRYSTAL UNITS

* * *

The Keystone Electronics Company
Contract No. DA-36-039-SC-75982
Order No. 43797-PP-58-81-81



INDUSTRIAL PREPAREDNESS STUDY ON
TIGHTER TOLERANCE CR-(COM-22)/U CRYSTAL UNITS

Combined Quarterly Progress Report
30 April 1958 to 30 July 1959

OBJECT OF STUDY

To modify and/or develop new fabricating techniques and equipments for the purpose of determining the feasibility of the production of tighter tolerance crystal units.

CONTRACT NO. DA-36-039-80-75982
ORDER NO. 43797-PP-58-81-87
SPECIFICATION No. MIL-C-3090-B

Report prepared by:
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Project Engineer

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1. ABSTRACT

Multiple cutting was tried in an attempt to increase accuracy in sawing wafers. Using a Felker Saw for this investigation presented problems that were too numerous to pursue and yet justify this added effort on this contract.

Efforts were then concentrated on increasing cutting accuracy using single blade operation on Felker Saws. It was found that the use of plywood blocks for mounting X sections and thin saw blades for cutting was responsible for a wide angular spread. It was then decided to try mounting X sections on Glass plates instead of wood and to use .045" thick saw blades instead of .025" thick blades. Results showed that the use of glass plates and thicker saw blades greatly increased cutting accuracy.

The next problem pursued was to transfer this accuracy into a productive yield. It was found that even though the saws cut accurately, the angular spread of a day's cutting production was extreme. The trouble was traced back to the X-ray procedure of checking trial cuts and the coarseness of the X-ray readings.

Corrective measures were taken by installing new gears in the mechanical portion of the X-ray to obtain more refined and sensitive readings.

After having satisfied the problem of cutting more accurate blanks, the next area of investigation was to develop a rapid and accurate means of measuring the exact angle of the diced blanks after the initial lapping stage. This was accomplished by Mr. John K. Miller, who developed a method whereby an operator merely feeds blanks into position on the X-ray and the angle measurement is displayed on the face of a scope. Approximately 3 seconds are required to obtain a reading. The accuracy of reading is within 1'. The possibility of human error is eliminated by the operator's not having to manipulate the goniometer arm and to interpret maximum deflection on a meter as being the correct reading. This system, which provides speed and accuracy, allows more selectivity in choosing closer tolerance blanks which, in turn, permits more flexibility of processing in the latter stages of the process.

In an attempt to determine the optical angle of cut and the tolerances required, extensive work previously done on control groups of crystals cut at specific angles, were re-evaluated and then re-processed. Consistent results of similar control groups were attained as a result of more refined measurements of the ZZ' angle, and better correlation of temperature end points. Optimum angles of cut for the frequencies specified in the contract were determined.

In order to take advantage of temperature characteristics emanating from blanks cut to the selected optimum angle, additional work was performed to develop an efficient method of adjusting the crystals more precisely at room temperature. Refining the scale of the frequency deviation meter yielded more accuracy. Continued investigations of soldering methods indicated the induction heat method to be most promising.

2. PURPOSE

The purpose of this Industrial Preparedness Study is to develop fabricating methods and production specifications for the fabricating of tighter tolerance crystal units operating within $\pm 0.0025\%$ of nominal frequency over the temperature range of -55°C to $+90^{\circ}\text{C}$. The designation given to this miniature fundamental mode crystal unit is OR-(XM-22)/U.

In order to accomplish the above this study has been divided into three parts. These three phases are as follows:

Phase I. - ORIENTATION ANGLE OF CRYSTAL BLANKS

This includes the study of cutting closer tolerance blanks productively, refined measurements of lapped blanks and angle shift during lapping.

Phase II. - FREQUENCY ADJUSTMENT OF FINISHED CRYSTAL UNITS

After establishing the optimum angle for tighter tolerance crystal units, it becomes important to frequency adjust these units at room temperature to a specific frequency in order to position the portion of the frequency temperature curve to the most advantageous point. This

necessitates the investigation of heat dissipated from the crystal, minimizing the effect of heat from the filament and the development of a good shutter system to precisely cut off the deposition of evaporated film at a specific time.

Phase III. FREQUENCY SHIFT IN CANNING AND SEALING OPERATIONS.

In order to retain the accuracy employed in selecting a blank having a specific angle of cut, and to utilize the precise frequency adjustment made at room temperature, it is important that an unpredictable shift does not occur in the canning and sealing operations. In order to prevent this, it becomes necessary to establish techniques for these operations so as to eliminate accompanying frequency shift, or if a frequency shift does occur to be able to predict the amount and direction in which it occurs. This will necessitate a thorough investigation of canning and sealing operations, preparation of holder parts, cleanliness of finished crystal units and stability and durability of the plating films.

After completion of these phases along with completion of preproduction samples and pilot runs,

The accumulated yield factors will indicate the feasibility of manufacturing tighter tolerance crystal units.

3. NARRATIVE AND DATA:

Extensive work has been done on the three phases of work as outlined above. Beginning with sawing wafers, multiple cutting was tried in order to increase accuracy in cutting. Since it has been firmly established that a high degree of accuracy is attainable in multiple cutting, using the P. R. Hoffman saw, it was felt successful results could be obtained by modifying a Felker Saw for use in multiple cutting. In addition, Mr. E. Schidlen, of Scientific Radio Products reported satisfactory results from the use of the Felker Saws for the purpose of performing multiple cuts.

Following Mr. Schidlen's suggestions, five eight-inch saws were mounted on a Felker Model-80 Saw. Initial results were encouraging. The blades were capable of cutting blanks within a 5' spread. This, however, only represents the cutting spread of each particular cut. The total

spread of fifteen wafers (three passes) averaged a total deviation of $10'$. This excessive total spread was partially caused by the shifting of the quartz block on the last pass. In order to minimize the shifting of the block, a larger amount of adhesive was applied in mounting the X section in order to build up a wall on the outer edges of the block. This reduced the total angular spread of the cut wafers to within $6'$. The cutting time for one pass (plunge cut) on a $.600''$ thick X section averaged $1'20''$. Many difficulties were encountered in trying to increase the cutting speed. In order to plunge cut in $30''$ it was necessary to reduce the weight of the counter-balance on the saw. This created problems whereby the wafers developed fractures as a result of excessive heating of the blades and quartz. These are only some of the problems encountered. Since this method of cutting was not selected in the final analysis, for this study, it is not germane to mention the associated problems in detail. It might be added, however, that the major problem encountered which prompted the discontinuance of multiple

cutting, was that it became necessary to clean up the cut, since plunge cutting with an 8" blade did not saw the bottom of the cut at the inner and outer edges of the X section.

Moving the table in a forward and backward motion a "step" developed in the wafers. This "step", which imaged the peripheral pattern of the saw blades, was caused by blade "wander" when cut in a transverse direction and inaccuracy on improper design of the saw ways.

Considering that the prime purpose of this contract is not to develop multiple cutting it was felt that to continue to pursue the problem inherent in multiple cutting could not be justified on this project. Efforts were then directed toward refining single blade cutting using the Felker Saw. Initial tests were made to determine the cutting accuracies of Felker Saws. In order to accumulate stronger supporting data, six saws were used throughout this phase of the investigation. X-sections, approximately 0.600" thick, were mounted on 1/4" thick plywood, using Glas-glu adhesive. The 3"x4" plywood blocks were held in a modified machinist type

vice which was firmly anchored to the saw table. The machinists vice is modified having a rigid metal plate that supports the plywood mounting block keeping the X-section parallel with the saw-table as the vice is being tightened. Saw blades used were 8" Felker blades .045" thick. Type coolant used is rolling mill oil. Approximately one dozen X-sections were wafered on each saw. The sections were marked, and the wafers from each block were numbered as they were cut. After X-raying each wafer, the tabulated results indicated that the first four wafers of each block cut had an angular spread of 2° , but with each succeeding cut the spread increased. This pattern of angle spread was evident from the data taken on each of the six saws. Analysis of the data and a study of the techniques, material, and fixtures used in the experiment indicated that the plywood block, on which the X-section was mounted, was shifting with each successive cut - after the first few cuts. It was then noted that the plywood block softened after becoming saturated with oil. Since the ac-

accumulation of oil increased with each succeeding cut so did the softness of the block, consequently causing shifting of the block which resulted in increased angular spread.

In view of the above, it was then decided to mount the X-sections on plate glass. Initially, problems developed whereby the adhesive would not form a satisfactory bond between the glass plate and the X-section. It was felt that the smoothness of the glass surface prevented a firm adhesion of the glue. Satisfactory results were attained by etching the glass and also by sand-blasting one surface of the glass plate on which the block was mounted. Although the results were satisfactory, an additional operation was involved in roughening the glass surface. Through these experiments, it was then learned that the glue was not adhering to the glass because of a thin oil film on the glass and not because the surface was too smooth. This oil film became deposited while the glass plates were exposed to the oil vapor emanating from the quartz cutting saws.

Performing the mounting operation in a room free of oil vapor eliminated this problem.

Once the problem of getting the mounted X-sections to adhere to glass plates was solved, test cuts were made and the results indicated the change was effective. The angular spread showed some improvement and did not increase with each successive cut. In order to try to further reduce this spread, it was decided to try thicker saw blades. An informal test performed, using thicker saw blades, showed improved results in relation to angular spread.

Controlled tests were then made to compare the difference between thin and thick saw blades and the difference between mounting sections on wood and on glass plates. Six saws were used for this evaluation:

The results are as follows

AGURZ NO. 1

SAW #1

SAW #2

SAW #3

SAW #4

| Saw # | THICK BLADE | | THIN BLADE | | THICK BLADE | | THIN BLADE | | THICK BLADE | | THIN BLADE | | THICK BLADE | | THIN BLADE | |
|-------|-------------|-------|------------|-------|-------------|-------|------------|-------|-------------|-------|------------|-------|-------------|-------|------------|-------|
| | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS | WOOD | GLASS |
| 1 | +4 | -1 | +2 | -7 | +3 | +1 | -1 | -3 | -5 | -4 | -6 | -4 | -1 | -3 | - | -3 |
| 2 | +2 | -2 | +1 | -7 | +1 | +1 | +2 | -2 | -5 | -6 | +3 | -4 | -1 | -5 | -1 | -4 |
| 3 | +7 | -5 | -3 | -7 | 0 | -3 | +5 | -2 | -9 | +1 | +4 | -5 | -4 | -6 | +2 | -2 |
| 4 | +8 | -10 | 0 | -8 | +2 | +2 | 0 | -2 | -9 | 0 | -3 | -2 | -3 | -2 | +2 | -0 |
| 5 | +11 | -3 | +1 | -7 | +3 | -9 | -2 | -2 | -10 | -4 | +3 | - | -4 | +7 | +2 | +3 |
| 6 | +8 | -3 | +1 | -8 | -2 | -9 | +6 | -2 | -8 | 0 | +4 | +3 | -5 | +2 | +2 | +3 |
| 7 | +9 | -4 | -1 | -11 | 0 | -8 | +10 | -4 | -12 | -5 | +8 | +3 | +3 | -2 | +7 | +1 |
| 8 | +10 | -8 | -1 | -9 | +3 | -4 | +7 | -4 | -12 | -6 | +4 | +2 | +5 | -4 | +4 | +4 |
| 9 | +10 | -9 | +7 | -8 | -2 | -4 | +12 | -4 | -10 | 3 | +6 | +2 | +1 | +6 | +7 | +1 |
| 10 | +11 | -13 | +6 | -4 | +1 | -5 | +7 | -8 | -8 | -2 | +4 | +2 | +3 | +10 | +8 | 0 |
| 11 | +11 | -14 | +9 | | +2 | -6 | | -6 | +4 | -1 | -3 | +14 | | | | 0 |
| 12 | +10 | | | | -1 | -6 | | -7 | +2 | | | -1 | +11 | | | |
| 13 | +7 | | | | -6 | -3 | | -7 | -1 | | | | +12 | | | |
| 14 | +12 | | | | -10 | 0 | | -9 | +3 | | | | +12 | | | |
| 15 | +10 | | | | -12 | | | -7 | -2 | | | | +16 | | | |
| 16 | +16 | | | | -9 | | | -6 | -2 | | | | +17 | | | |
| 17 | | | | | | | | -8 | | | | | -7 | | | |
| 18 | | | | | | | | -8 | | | | | +8 | | | |
| 19 | | | | | | | | -8 | | | | | | | | |
| 20 | | | | | | | | -19 | | | | | | | | |

TOTAL 14' -13' 12' -6' 5' 10' 11' -2' -34' 10' 14' 8' 21' 16' 10' 8'

EXPEND

SEE NEXT PAGE FOR DATA ON Saws #5 & #9

It is evident from the data above, that the use of glass mounting blocks and thicker saw blades increased accuracy in cutting. It was interesting to note the accuracy attainable through the use of the Felker Saw. Data, such as illustrated above, was accumulated bi-weekly from production work, for a period of eight weeks. During this period, minor variations in methods of maintaining the saws were employed and data accumulated bi-weekly indicated that the Felker Saws were capable of cutting blanks to within $4'$.

Distribution curves showing the angular spread of diced blanks cut in production, however, showed a total spread of $30'$. Since these diced blanks were measured for angle after the first rough lapping stage, it was suspected that the change was due to the angle shifting in lapping. Studies in the past indicated a negligible change in angle due to lapping. It was decided to make additional tests using approximately 2,000 diced blanks. The blanks selected were $.045''$ thick, free of burrs, parallel, and registered the same angle of cut on each side. Test results verified that $.010''$ removal of stock due to lapping did not cause any serious

shift in angle. Lapping an additional .010" off this same group of blanks gave similar results.

Work was then directed toward establishing a system used in making trial cuts and authorizing corrections in sawing wafers. The normal practice was to make a trial cut, measure the error on a Phillips X-ray, make the correction by adjusting the saw table, make successive trial cuts until the wafer reads to within 2' of the required angle. Once the "check" piece was within tolerance, the operator continued to cut the remainder of the block without any further checks. In trying to minimize the total angle spread of wafers cut from X sections it was decided to check the center wafer cut from each section, and make necessary corrections before continuing to cut the remainder of the block. Doing this only slowed up the production rate and did not reduce the total angle spread of the daily production of diced blanks. After additional tests were made it was determined that the extensive spread in cutting was caused by the inaccuracy of measurement in checking the trial cuts. It was found that

the backlash in the teeth of the mechanical portion of the goniometer arm on the Phillips X-ray machine accounted for a possible error of 4'. In addition, it was found that the broadness of the intensity curves as read on the X-ray intensity meter could contribute an additional error of 4'. Considering that the saw is responsible for a 4' spread and a possible 8' error due to X-raying (backlash and broadness of intensity reading) the trial cut, if these errors were applied in one direction the total error could be as high as 12'. Apply an additional error of a few minutes due to the human error of the operator in making corrective adjustments of the saw table, the reasons for a total production angular spread of 20' becomes evident.

In order to try to retain the cutting accuracy of the Felker Saw, certain corrective measures were taken. After installing new gears and engaging teeth on the goniometer arm portion of the Phillip's X-ray, and installing a double crystal diffraction system, which was procured from Scientific Radio Products Co. It was possible to maintain a total average angular spread of approximately 6'.

Even though it is known that tighter tolerance crystal units will require the use of crystal blanks having less spread than 6', it is felt that if a 6' to 8' spread in daily production could be maintained in cutting it would be satisfactory. It is felt that greater accuracy in cutting productively is impractical using the type of saws existing in the crystal industry. Unless, however, the industry were equipped with the P.R. Hoffman Quartz Cutting Saws. If it is determined that tighter tolerance crystal units are going to require 1' or 2' blanks, then these blanks will have to be obtained by selection. Selecting 2' blanks from 6' blanks rather than selecting from 20' blanks is much more practical and should not prove to be serious in production.

Determination of the proper angle and angular tolerance for tighter tolerance crystal units, and the method of cutting blanks to meet these requirements, represents only a portion of the problem. Unless the angle of these blanks can be measured accurately and rapidly, the production of tighter tolerance crystal units will remain a highly specialized type of unit which could not be mass produced without severe losses

and production limitations. Mr. John K. Miller, long associated with The Keystone Electronics Company, developed a method of X-ray measuring crystal blanks that makes it possible to perform measurements accurately and rapidly. This system eliminates human error normally associated with manual operation and interpretation of X-ray readings by the operator.

Mr. Miller devised a method to have the goniometer arm produce a D. C. voltage whose amplitude is directly proportional to the position of the arm. This voltage is applied to the horizontal deflection of a 7" long persistence deflection cathode ray tube. The face of the tube is calibrated in minutes to represent minutes of arc of movement of the goniometer arm. The arm is mechanically swept through an arc of $\pm 15^\circ$ of any selected nominal angle. The output from the Geiger-Mueller circuit is fed to the vertical deflection plates. With a crystal blank positioned in the apparatus for measurement, the mechanical sweeping of the goniometer arm through the range of $\pm 15^\circ$ of a desired angle, will displace the cathode ray vertically as the crystal under test passes through its angle of diffraction. This displacement,

In the form of a "pip", will register on the calibrated face of the scope clearly indicating the exact angle of the cut of the blank being measured. The accuracy and repeatability of measurement is within 30 seconds of arc. This system was built into a Phillips X-ray to which was added a double crystal accessory to increase sensitivity of readings.

X-ray standards are used to set end points of scope calibration. This range between the end points can be set to any desired spread. The time taken for a 30° sweep is three seconds.

This system eliminates the necessity of the operator tuning for and determining the point of maximum deflection of the meter which is difficult to identify because of fluctuation of line voltage, amplified tube noise, etc. Using this method the amplitude of the "pip" becomes irrelevant to the position of the "pip". The development of this apparatus makes it possible to read blanks rapidly and accurately. Blanks to within 1° of a desired nominal angle can be read and selected five times faster than blanks processed through the standard measuring systems that are used throughout the crystal industry. In addition,

the greater accuracy attained by this system surpasses other systems on a yield basis. The speed and accuracy is accomplished by an operator with little, or no experience. It is only necessary for the operator to position the blank in the machine and after reading a number where the measured blank registers a "pip" on the large scope face, file the blank in a corresponding category illustrated on the blank filing rack.

To be able to read blanks with this speed and accuracy through the use of this system, eliminates any undue hardships in tightening tolerances on crystal blanks selected from cutting for use in producing .0025% crystal units. The efficiency of this system makes it possible to establish a greater safety factor in selecting 1' blanks from cutting thereby increasing the yield of finished crystal units from temperature test, which in turn makes it possible to relax tolerances, or use normal techniques, in the final plating and soldering and sealing operations.

In order to establish optimum angles of cut, control groups of crystal units were fabricated having specific orientations of angles. The orientation of these groups was spaced 2' apart.

Difficulties were encountered in the analysis of the frequency-temperature characteristics of the control groups. These difficulties were largely due to temperature correlation of the "slugs" used in heating the crystal units. Mis-correlation was traced back to the mismatch of thermistors used in the heating "slugs".

Once the optimum angle of cut is established for the purpose of minimizing frequency shift over the temperature range it becomes important to have the center portion of the "S" shaped curve positioned at a specific point so that the extremes of the frequency-temperature curve fall equally on both the positive and negative sides of nominal frequency. Because the control of the centering of this curve is governed by adjusting the crystal unit at room temperature to a specific frequency continued experiments were carried on to make this adjustment more refined and repeatable.

A shutter system was employed within our evaporation-to-frequency adjusting system, for the purpose of preventing the thermal inertia of the plating filament from continuing deposition of plating onto the crystal - which causes the frequency to go beyond the specified point -

after the operator releases the switch which controls the heat of the filament.

After trying the shutter system and getting unsatisfactory results because of mechanical problems whereby the shutter became bound within the solenoid housing, it was decided to refine the scale on the deviation meter which indicates the frequency of the crystal unit as it is being adjusted. Since one division ($1/16''$ wide) of the deviation meter represents 20 cycles, meter fluctuation, human error of the operator and thermal inertia of the plating filament sometimes caused a cumulative error whereby the crystal unit after frequency adjustment would be as far as 3 to 4 divisions (60 to 80 cycles) away from the chosen point of adjustment.

Reducing the range of the scale on the frequency deviation meter, whereby one division of the scale represented 4 cycles instead of 20 cycles, beneficial results were derived. Results of continued use of this system for frequency adjustment showed a 50% increase in plating accuracy.

Additional work was performed
on Phase III - Frequency Shift in Canning
and Sealing Operations.

Methods of soldering evaluated were the hot plate type, induction heat, and solder track. As stated in the last report, the best results based upon frequency shift due to soldering, were attained from the use of a slotted aluminum panel positioned over a hot plate. The amount of frequency shift, though slightly more than the amount attained by induction heat, was uniformly consistent. Since the frequency change was uniform, it was felt that the amount of change could be predicted and compensated for in the previous operation of frequency plating.

Continued use of the hot plate system showed variations from results attained initially. These variations occurred where an attempt was made to increase the production of this system by increasing the loading stages (slots on the periphery of aluminum plate) from twelve to thirty-six positions. It was then found that it was impractical, even for the most experienced

operator, to coordinate loading and unloading so that each crystal unit would be subjected to a uniform amount of heat and a similar "heat-up" and "cool-off" cycle. This non-uniformity in temperature cycling resulted in variation of frequency change in crystal units that were soldered and therefore the amount of frequency shift could not be compensated for in the previous operation of frequency plating.

As a result of the above, it was decided to re-evaluate soldering experiments previously performed using the soldering track and the induction heater. Re-evaluation showed that the results of the use of the soldering track were similarly unsatisfactory and for the same reasons as the thirty-six position hot-plate.

This problem was overcome by controlling the heat cycle of the induction heater. In the initial evaluation the amount of heater current was fixed; however, the time cycle was not. Since during this operation the operator sometimes applied flux

and varying amounts of solder, the length of time of the heat cycle was left to the discretion of the operator. Although this approach yielded satisfactory seals, it was learned that the variation in heating cycle gave variations in frequency change due to soldering. In order to verify these findings, control groups of crystals were soldered whereby the heating time was fixed and the holder parts were more heavily pre-tinned in order to eliminate the application of additional solder during the heat cycle. Results were satisfactory and the amount of frequency shift was more uniform.

4. CONCLUSIONS

Experiments performed on single blade cutting operation prompted certain improvements in techniques and equipment design. These improvements, which refined the operation, make single blade cutting using the Felker Saw suitable for the production of tighter tolerance crystal units.

After attaining diced blanks having less angular spread, a compatible system for measuring these blanks accurately and rapidly was required. The development of this system is described above.

Based upon the work performed thus far, it is believed that blanks for application to tighter tolerance crystal units can be cut abundantly at specific tolerances and X-ray measured with extreme accuracy with little or no difficulty.

Optimum angles with a tolerance of ± 1 have been established for each frequency specified in the contract.

A shutter system in conjunction with a selective frequency amplifier will eliminate the two remaining problem areas in

precise frequency adjustment of the crystal unit.

Evaluation of soldering techniques indicate that induction heat is the most efficient method of soldering together holder parts.

5. PROGRAM FOR NEXT PERIOD

At the present time pre-production samples are being fabricated.

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