The Rigaku Journal
Vol. 5/ No. 2/ 1988

## Technical Note

# FULLY AUTOMATED PIEZOGONIOMETER (Automatic Quartz Blank Classifier)

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The "FAP" (Fully Automated Piezo goniometer) automatically measures the deflection angle of the cut plane of the AT cut quartz crystal wafer. It then sorts these quartz blanks into several grades according to the angle of the cut quartz plane. Production of high quality quartz crystals, with good temperature coefficient, is the goal of this sorting. "AT" cut quartz crystals are used to set a very precise operating frequency of computers, cellular phones and two way radios, etc.

The FAP System requires an operator to load a hopper with AT cut quartz blanks. The size ranges from 9 x 9 mm to 11 x 11 mm square with a thickness range of 0.2 to 0.5 mm. The FAP System will then carry out the fully automated deflection angle measurements and sort.

The measurement precision is ±30 seconds and can be continuous in operation. Sample processing is implemented at the rate of about 500 pieces per hour for one stage, such as in the target range of 7'. Each FAP unit has two working stages. It is capable of processing samples at the rate of about 1,000 pieces per hour, or 24,000 pieces in a 24 hour/day.

The FAP system is designed for measuring the deflection angle of each AT cut quartz blanks by X-ray diffraction techniques and then sorts the sam-ples into the prescribed deflection angle sections. Compared to a manual system, the FAP not only permits operator-labor savings, it also eliminates the wide variations in the quartz blank quality. The use of the fully automatic FAP unit results in a yield of higher quality quartz blanks.

In order to minimize frequency drift, due to ambient temperature changes, the crystal blanks must be cut in a specified direction with respect to the crystal axis. AT cut blanks are used in almost all cases where it is generally important that the temperature coefficient should fall within ±20 x $10^{-6}$ of the fundamental frequency over a temperature range of between -55°C and +105°C. In terms of the angular deflection, with respect to the crystal axis, this is tantamount to ±1', or even to ±30" in a more critical application. It would be very difficult to cut all blanks to within ±30" during the quartz cutting and lapping process. Consequently, it be-comes necessary to inspect the deflection angle of the quartz blanks by means of X-ray diffraction method and to classify them accordingly.

Fig. 1 shows the optical principle of the FAP system. X-rays are generated from a copper-targeted X-ray source and after passing through a beam defining slit, they impinge on the quartz sample at point P. The detector is installed at a diffraction angle of $2\theta=26.66^\circ$. When the quartz sample is rotated on the axis of point P and the lattice plane $(01\overline{1}\overline{1})$ comes to the position of $\theta$=1 3.33 degrees as a result, then X-ray diffraction will take place. Diffracted X-ray then enter the detector to cause the pointer on a meter M to swing. The deflection angle $\delta$ is an angle formed by the quartz sample surface and the lattice plane $(01\overline{1}\overline{1})$. The deflection angle $\delta$ of the-AT cut blank is 2° 58'. The lattice interplanar spacing (d) of the (01 ff) plane is 3.343Å. Driving for ($\omega$) rotation of the quartz crystal is made with a ($\omega$) scan, or stepping motor, and the rotation angle is controlled with the number of pulses. The reference point for ($\omega$) rotation is determined by the datum point.

A microcomputer sequence control is made for this system. Prior to automatic measurement, the angular reference point is to be determined by the Cal Mode operation by measuring a standard sample, whose deflection angle is already known. It is possible to shift this reference point by applying offset. By reading the relative angular value with respect to the reference-point angle, sorting is conducted according to each deflection angle measured. A reduction in the measurement time and improvement in the measure-

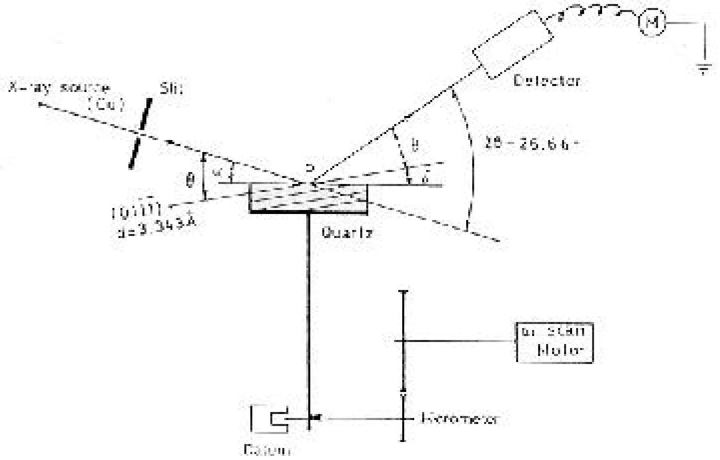

**Fig. 1** Diagram of optics of automatic piezogoniometer

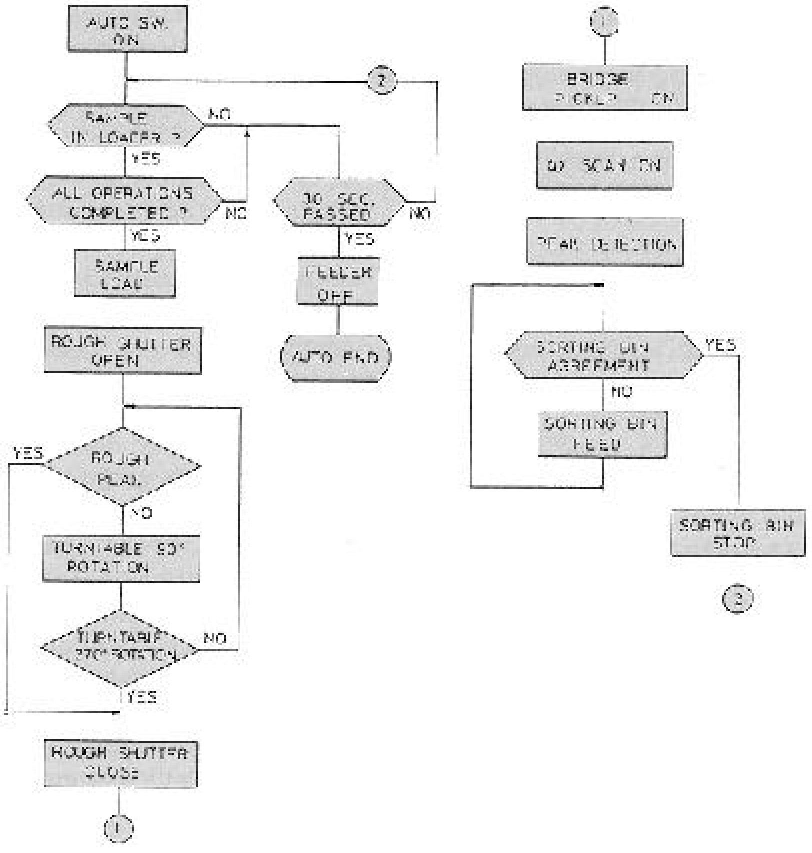

**Fig. 2** Flow chart of automatic sequence

ment accuracy are the benefits derived through this measurement procedure.

Fig. 2 illustrates a flow chart of the FAP automatic sequence. As the hopper is fed with quartz samples, they are arranged in order by a vibratory parts feeder. With the "Auto Switch" turned on, a sample arranged at the head of the group is carried by a robot to a loader by vacuum pickup. When the sample has been brought to the loader and if measurements in the preceding steps have all been completed, then the sample is transferred to the measuring section on a turntable. The turntable holds the sample and rotates it in 90° increments at a time. The sample has been brought to the turntable by "Sample Load" operation. A jet of compressed air is used to clean the blanks surface. Then the "Rough Shutter" is opened to irradiate the sample with a divergent X-ray beam having an opening angle of about 30'.

Fig. 3 illustrates how a possible initial orientation of a sample can face the measurement direction. The diffracting lattice plane $(01\overline{1}\overline{1})$ of the AT cut quartz blank forms an angle of about 3° with respect to the crystal surface.

The sample is square and one edge is cut parallel to the X-axis. The diffraction condition is met when the angle Alpha made by the incident X-ray beam and sample surface is at 10.33', and the incident beam angle to the diffracting plane is $\theta$=13.33°. When the sample is fed in a way as shown in Fig. 3(d), diffracted X-rays will be detected immediately. On the other hand, when it is fed as in Fig. 3(c), diffracted X-rays will be detected upon 90° rotation of the sample. In the same fashion, upon 180° rotation in the case of Fig. 3(b) and upon 270° rotation in the case of Fig. 3(a). The probability that the sample is fed in any of these four directions is 25%, respectively. After diffracted X-rays are detected, the sample direction is as shown in Fig. 3(d). The "Rough Shutter" will close and the sample is pulled up to the bridge fixture by vacuum pickup. The bridge holds the sample at three points. With a thin X-ray beam approximately 4' wide that is incident on the sample, the $(\omega)$ rotation is performed. The intensity of the diffracted X-rays are detected by a scintillation counter. Thereby the mid-point between the angles P1 and P2 is measured as the peak position when the set intensity level is passed through (Fig. 4).

The measured peak position is identified as an angular difference from the reference point. The reference point was obtained by measuring the standard sample beforehand (including offset) and stored in the computers RAM memory. Measured samples are classified into seven sorting bines corresponding to the respective deflection angles. Three different angular widths are available for one section, for example 2' (14' RANGE), l' (7' RANGE), and 0.5' (3.5' RANGE). The setting can be done according to the measurement purpose. Samples which fail to sort into any of the seven sections will be sorted into either a +OUT, or a -OUT box (Fig. 4). The relation between the peak position and the sorting bin is as shown in Fig. 4. The 0' reference point is set from the measurement of the standard sample. The goniometer starting point for $(\omega)$ scan differs according to each RANGE. As in Fig. 4, with 0' as the base, the goniometer starts from the minus side at a point of about 9.75' with 3.5' RANGE, about 11.5' with 7' RANGE, and about 15' with 14' RANGE. To shorten the measurement time, the $(\omega)$ scan is terminated as soon as P2 point is detected and the operation will proceed to the next step.

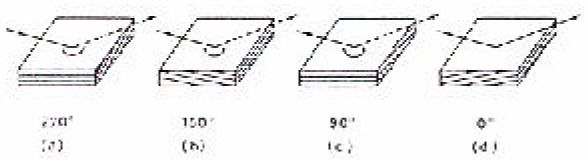

**Fig. 3** Possible initial orientations of rectangular crystal blanks

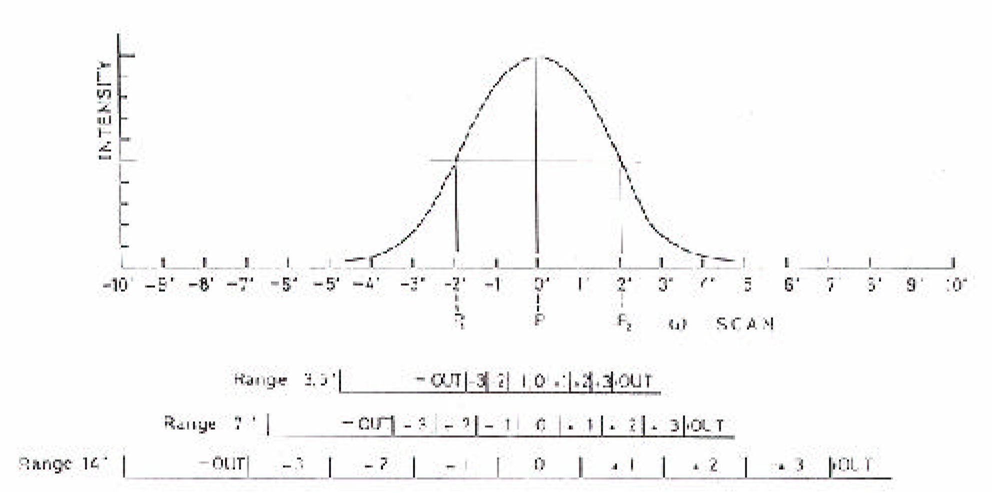

**Fig. 4** Acceptance span for classifier bines. Striations accompanied by lattice constant changes, as well as a contrast due to a large lattice plane.

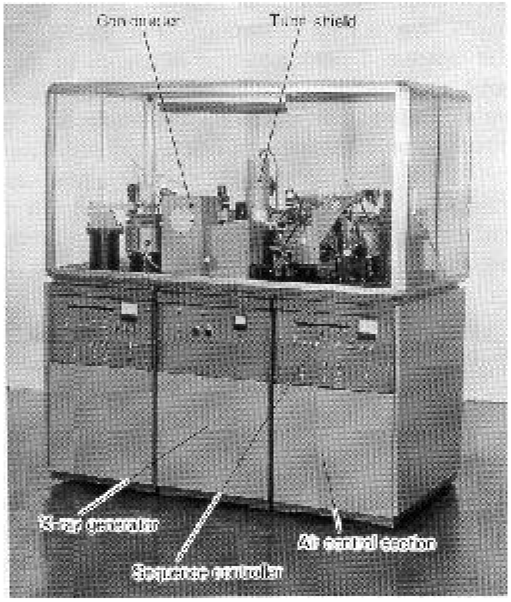

**Fig. 5** Fully automated piezogoniometer.

Fig. 5 shows an overall view of the FAP system.

The FAP system is composed in such a way that the X-ray tube is positioned at the top of the center cabinet. Each goniometer station, complete with it's own sequence controller, counting circuit, parts feeder, and sort station has its own cabinet. Each stage can be operated independently from the other and are not directly connected so as to isolate vibrations. The system uses an air cooled Cu target X-ray tube with a rating of 30 kV, 5 mA. The X-ray focal spot size is 0.1 x 4 $mm^2$ when viewed from a 6° take-off angle. The tube voltage is fixed at 30 kV, while the tube current is variable from 0 to 5 mA. A scintillation counter (SC) is used as the detector. The allowable sample size is 9 to 11 square millimeters and 0.2 to 0.5mm thick. With the parts feeder and the hopper combined together, it is possible to accommodate up to 8,000 pieces at a time on either side. Each stage permits measurement at the rate of about 500 pieces per hour in the case of 7' RANGE. For example, when both stages are operated together, the processing ability will become as high as 24,000 pieces per a 24 hour/day. Compressed air and vacuum are used to transfer the sample to the measuring section and for the cleaning of the sample's surface. The pressure of the compressed air sent from a compressor is approximately 6 to 7 $kg/cm^2$. This pressure is lowered to 4 to 5$kg/cm^2$ with a reducing valve and the resulting compressed air is then fed to the bridge and a decompression device. The air supply to the required places is made by on-off operation of an electromagnetic valve. Further, a vacuum is produced with the venturi type decompression de-vice, so as to conduct sample pickup with the robot, loader, turntable and bridge.

For precision measurement of the deflection angle of samples special attention must be paid to the way the sample is held. Variations in sample holding would directly result in variations in the angle measuring accuracy. To this end, the FAP system employs a 3-point contact method with the bridge for sample holding to realize high precision measurement. Cleaning of the sample surface by air shower is also made prior to sample holding.

Another requirement for precision measurement of the deflection angle of samples is to maintain parallelism between the sample surface and the X-axis. This must be done at the cutting and lapping fabrication process during the manufacturing of the quartz crystal blank. It is important to take care of the following in order to achieve precision measurement of the deflection angle. For example, the angle $\varepsilon$ made by the sample surface and the X-axis direction, shown in Fig. 6, should be minimized as far as possible. Also, one edge of the sample needs to be cut precisely at right angles to the X-axis whenever the sample is cut into a rectangular shape ($\varphi$). The incident X-ray beam should be prop-erly directed normally to the X-axis ($\varphi$).

Fig. 6 indicates that an error will be included in the measurement of the deflection angle because of the aforementioned $\varepsilon$ and $\varphi$. For instance, suppose the X-ray incidence is made at $\varphi$=l° on a sample in which $\varepsilon$ is 40°. This will result, upon measurement, in a value of about 40" greater than the true value of the deflection angle. It is therefore imperative to keep $\varepsilon$ and $\varphi$ to within ±10' and ±20', respectively, in order to measure the deflection angle with accuracy.

Fig. 7 shows measurement data on long term stability. This data was obtained by repeated measurement over 17 hours by the automatic sequence operation with a sample kept adsorbed to the bridge. The measurement results of the deflection angle were printed out once per 50 times and plotted. The X-ray tube voltage and current applied were 30 kV, 2 mA and the room temperature variations during the measure-ment were 23±5°C. The reproducibility obtained on the occasion was ±7.5" at $3\sigma$ in terms of reproducibility. This data represents the reproducibility of the FAP system over long hours where there

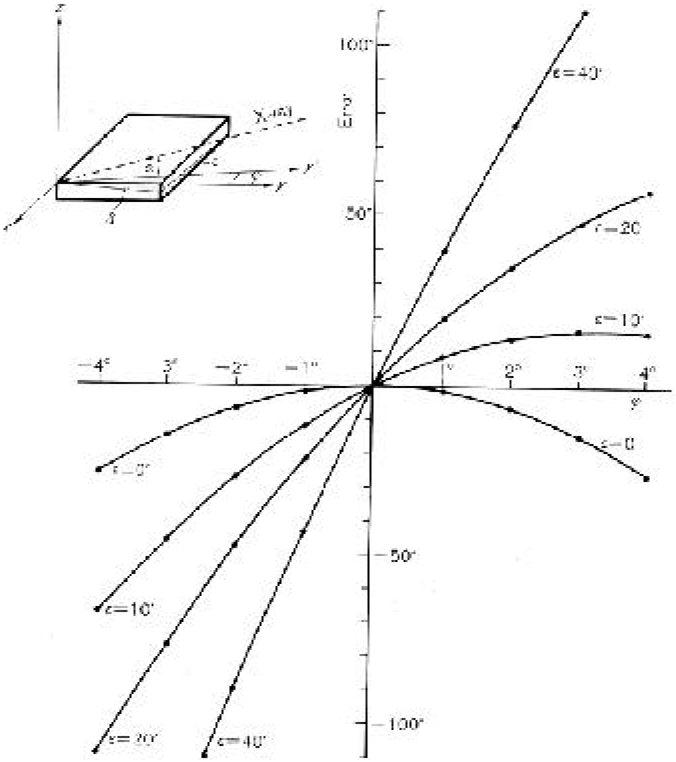

**Fig. 6** Measurement error diagram.

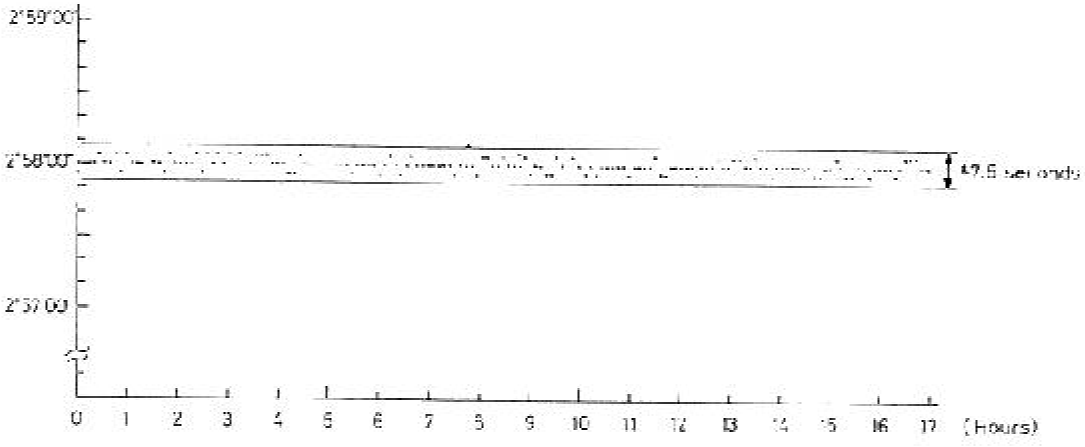

**Fig. 7** Long term stability

is no fear of variations in the sample adsorption reproducibility.

Fig. 8 shows measurement data on the measurement precision of the FAP system. For this examination, repeated measurement of the deflection angle was conducted 87 times by feeding the same sample with its surface kept on the same side and in the same direction. The results were printed out for subsequent plotting. The reproducibility obtained was ±14" on 3 Sigma. The data results are inferior to the results in Fig. 7. The reason is that variations, in the reproducibility of sample pickup by the measurement bridge, were involved in this case. Variations in sample pickup and placement will be affected by roughness of the sample surface, or sample bending, etc. Minute particles of dust deposited on the sample surface can deteriorate the measurement's precision as well. It is imperative to clean the samples prior to measurement and to keep the room clean from dust. The above data

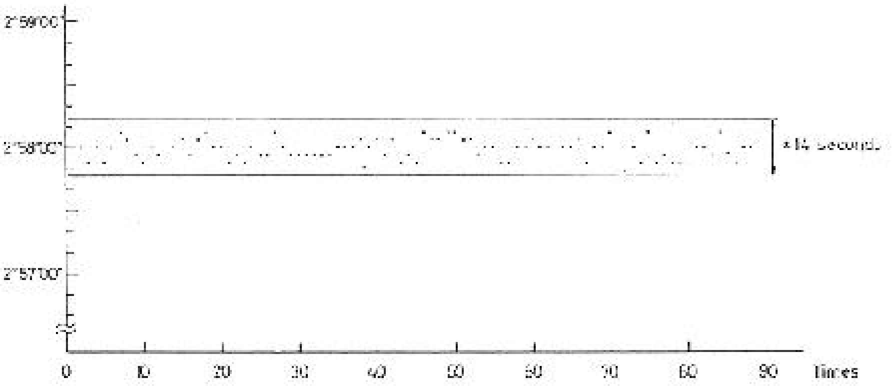

**Fig. 8** Repeatability of positioning and classification.

proves that the FAP system has a precision of 3σ = ±14', in terms of reproducibility. In RIGAKU's written specifications, however, it is stated as ±30", because we have to take into account the fact that the FAP is a system for use in the production field. Its measurement precision may be affected by dust and other elements deposited on the bridge surface in the course of long production runs.

The RIGAKU FAP system can offer a very cost-effective tool for manpower savings and definite quality improvements in the production of quartz crystal blanks. There are, at the present, approximately 70 sets FAP system installations around the world, providing X-ray inspection of the quartz crystal blanks.