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DESIGN AND USE OF MULTIPLE-BLADE SLURRY SAWING IN A PRODUCTION ATMOSPHERE

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WHAT IS MULTIPLE BLADE SLURRY SAWING?

Since there are many arrangements, designs and uses of these saws, the best approach to the understanding of the mechanics is to consider the process or technique. This consists of arranging multiple bands of steel in a frame and reciprocating the frame with the bands in contact with a workpiece, while simultaneously applying abrasive at the point of contact. As a result of this arrangement, the blades wear slots in the workpiece and, if the process is carried on long enough, the blades progress through the piece resulting in several parts or wafers. An early use of a device employing this technique was the dressing of large quarry block into smaller, flat building stone or into tomb stones. This is commonly called "loafing" in reference to the similarity between the workpiece as cut and a sliced loaf of bread.

WHAT SUB-SYSTEMS ARE REQUIRED?

The basic parts required to saw are:

A. Blade Frame. This component carries the steel blades, keeps them in proper spacing such that the slices will be uniform one to another and of even thickness, and in the case of the stone saws, imparts the reciprocating or oscillating sawing action.

B. Drive System. This system is the motive power into the saw and includes the prime mover, speed reduction, and conversion from rotary to reciprocating motion.

C. Travel Guide. The blade frame must traverse in a straight line in relation to the blades and it is the guide system that establishes the travel line.

D. Feed. As previously mentioned, the blades and the workpiece are brought into and kept in contact while the sawing action progresses. It is the function of the feed system to apply and maintain this contact.

E. Feed Guide. As with the travel guide, the feed guide must raise the workpiece, or lower the blade frame, as the cut progresses such that the cut remains in the plane of the blades.

F. Abrasive System. This system must mix, transport and gather the abrasive slurry for re-use and must do so in a very efficient manner. The working parts of the machine must be completely protected from the abrasive, lest the parts operate with abrasive on them and experience high and abnormal wear.

Multi-blade sawing existed in this crude stage up until the mid 1950's with few attempts to establish the technique as a precision process. It was the advent of the electronic grade silicon that prompted the design and construction of a precision multiple blade slurry saw (MBS) and the patenting of a technical breakthrough which made the precision possible.

Grover Hunt, who designed the multiple blade power hacksaw, came into the problem as no stranger to material processing. He was a principal character in the cast of pioneers in the Carlisle based crystal industry and, as such, knew first hand the problems of sawing thin fragile parts.

The basis for the patent, No. 3,079,908, and the breakthrough to precision was in the blade frame construction and the holding and tensioning of the blades in the frame. In the Hunt machine the blades are spaced apart with solid spacers and the ends squeezed with compression bolts such that the blade to spacer friction is initially low enough to allow the blades to slip and equalize. Then the compression bolts are tightened such that the friction is high enough to resist high tension, 80% of yield, which is put into the blades by the blade frame.

After designing and building the saw, many attempts were made to saw silicon with the device. The success of these attempts was limited and the emphasis was put on multi-blade quartz slicing. Several units were built and sold as the "Berkshire" Machine until the patent rights were sold to Norton Co. and then to Varian. The machine gained a substantial foothold in the quartz industry, but never proved out in the electronic grade silicon wafering industry.

In the last 5-8 years a Swiss Company, Meyer & Burger, has been marketing a similar saw in the U.S. and has taken some necessary steps to increase the precision of the saw. In addition, several new designs have very recently appeared on the market since the original Hunt patent coverage has expired. Various attempts have been made to address the requirement of each sub-system.

DESIGN PROBLEMS AND EXISTING SOLUTIONS

The requirements of the blade frame on a modern precision machine have become much more stringent. The blade frame must resist gigantic loads for the size, upwards of 100 tons without appreciable twist. It must be relatively lightweight so that the mass loading during reciprocation is low, if in fact the designer opts to drive the frame. Provision must be made to adjust the absolute track and to also adjust the blade pack for parallelism.

The available blade frame design alternatives are to make the frame massive to resist warpage and either limit the stroke speed or fix the blade frame and reciprocate the workpiece, to use the original system as patented by Hunt, or to use the frame within a frame concept as does the Meyer & Burger.

The requirement on the drive system is simple and straight forward, without any weight or size constraints. It is to deliver the power to the reciprocating member with a reliable and trouble free system. The real problem is the reversing load through the Pitman Arm, (if one resorts to the classical steam engine drive) to the Drive Pin and back through the speed reduction to the motor.

Both of the saws presently in use have Pitman Arm type drives, or connecting rod ties to a flywheel. This gives the classical sinusoidal velocity to the blade frame (work table in the case of a P. R. Hoffman machine) and therefore, sinusoidal force in the drive system. This reversing load is very hard on a worm gear reducer, and P. R. Hoffman has therefore precluded this problem by using a three stage "V" belt reduction.

The travel guides must be as true as possible, since the target for blade alignment is .0002" or less. Inaccurate ways produce wide kerf and broken parts. The problem is not in getting the ways true but keeping them so. Both Varian and Meyer & Burger, as previously mentioned, reciprocate the blade head. They guide the head with an inverted "V" way and a flat; classical grinding machine design. This is a very acceptable way to attack the problem. The ways, being cast iron, can be hand scraped to very accurate tolerances and form an easily lubricated surface on which to slide the blade frame. The problem is twofold. One, the ways are difficult to protect and when contaminated with grit they rapidly lap out of line. Secondly, in the case of a Varian machine as well as some of the newer designs, the scotch yoke type drive places an off-center load on the head which must be countered by side loading in the travel guides. This gives rise to preferential wear which quickly destroys the true "track" built into the way system. P. R. Hoffman and Meyer & Burger have both precluded this off-center loading by placing a slider, steam locomotive style, between the rotating member and the connecting rod. The ways of the slider accept the off-center load and will wear. This will not affect the tracking however, since care in connecting the slider to the blade frame precludes a moment transfer. P. R. Hoffman does not use a hand scraped "V" and flat ways since we have elected to reciprocate our work table. We have used preloaded ball bushings and precision ground round ways. These have proven to be true to within 50 microinches over full stroke.

The basic requirement for the feed pressure system is accuracy. When the operator selects a feed force, it must be the same today as last week. Most everyone uses air pressure cylinders to push the work into the blades; Meyer & Burger use hydraulics. The problem with the direct method is friction and change in friction with temperature. Therefore, every effort must be made to keep down the friction. Using low friction cylinders or bellows type cylinders, and keeping the feed guide system well lubricated and as free as possible are acceptable approaches to the solution of this problem.

In the design of the feed guide the tracking requirements on the guide are as stringent as on the travel guide and the same approach has been used. Meyer & Burger use the hand scraped double "V" with adjustable gibs. This is a very acceptable arrangement but, since we have found round ways and ball bushings accurate enough for travel, we likewise found the die-set feed system more than adequate. As with the travel guides, grit contamination in this system is catastrophic.

In designing the abrasive slurry flow system, as discussed throughout, one must recognize that grit contamination is disastrous and therefore the shielding must be 100% efficient. The other functions of the system, mixing and delivering the abrasive slurry, are important considerations, but not nearly as critical.

EXPLORATION OF FUTURE DESIGN IMPROVEMENTS ON THE P. R. HOFFMAN SAW

We have concentrated our design efforts on the elimination of internal stresses and pounding due to load reversal, and feed inaccuracies due to friction as we recognize the solution of these two problems should provide the greatest dividend. The obvious solution to the load reversal problem seems to be to store the slow-down energy in some device, such as a spring or tank of air, and use it to supply the inertial start-up at the stroke start. We have tested such an arrangement using the spring system, but have found spring noise and guide slide defeated the system. Work in this area is still underway.

Feed inaccuracies do exist in most machines we have seen and the most promising arrangement proposed to date seems to be using the pnuematic or hydraulic cylinders as a servo device only, and sensing the blade pressure either at the chuck or on the blades. In an arrangement such as this, the best bet might very well be using hard feed (screws, racks, wedges, cams, etc.) in place of the cylinder feed. P. R. Hoffman is investigating this system also, and should have a protype on our saw in the middle future.

USE OF MBS IN PRODUCTION

Familiarity with the various design considerations and problem areas presented above will enable the reader to identify the key controls necessary for satisfactory operation of the MBS saw in production. In setting up the saw for a wafering run, the operator must take care to properly install the blade package so that proper alignment and blade tensioning are achieved. Appropriate adjustment of vertical feed pressure at the start, and maintenance of proper pressures throughout the run, are essential to achieving good wafer quality. Other factors contributing to wafer quality are slurry vehicle and abrasive ratio, slurry volume and delivery system, and vehicle, abrasive and blade specifications. It will be found that specification of these last factors is dependent on the material being wafered and the desired finished wafer specifications.

TYPICAL MATERIAL WAFERED BY MBS PROCESS

Materials which are suitable for MBS wafering include silicon, germanium, crystalline and fused quartz, crown and flint glasses, ferrite, tantalates, niobates, carbides, ferrous and non-ferrous alloys, ceramics, and various crystalline and amorphous specialty materials used in optical and electro-optical applications. The MBS process has been utilized at P. R. Hoffman Co. (for approximately 8 years) to wafer piezoelectric quartz crystal blanks and many of the various materials listed above. During this period, well over one million production saw hours have been logged.

GENERAL PRODUCTION CONSIDERATIONS

The transition to MBS from traditional O.D. diamond blade slicing was justified by the savings resulting from minimized kerf losses, minimized sub-surface damage, and improved surface quality off the saw. These benefits allowed wafering much closer to finished thickness specifications, which provided better material utilization and the elimination of some intermediate processing operations.

The maximum allowable size of the workpiece to be wafered is, ot course, dependent upon the clearance available through the blade frame. On most of the equipment available, workpiece width is limited to 6 inches and available depth of cut is approximately 6 inches. Note that depth of cut capability does vary significantly depending on machine manufacturer. Working length of the workpiece can vary from roughly 7 inches on the Varian saw to 9 inches on the P. R. Hoffman saw. This length is also limited by the desired wafer thichness to be produced. Sawing of very thin wafers allows enough blades to be stacked in the blade frame to result in tensioning load requirements which exceed the capacity of the frame.

Although it is not necessarily representative of the limits of the MBS process, the following presentation of MBS production parameters experienced in the ongoing production activity at P. R. Hoffman Company is intended to enable the reader to assess the applicability of the process to his current or future slicing requirements. Along with our traditional production of piezoelectric quartz crystal blanks, we manufacture several custom optical components and provide slicing service to various industries which further process wafers of most of the above listed materials.

Using the MBS process, wafers of .015" thickness to greater than .300" are routinely produced from materials ranging from .090" diameter to over 5" in diameter. Typical quartz crystal blanks range from .350" square to .750" x 2" rectangles. Due to standardization of blade thickness and abrasive particle size to satisfy other production constraints, the vast majority of our wafering is accomplished at a kerf loss of .013" per wafer. Various combinations of available blade and abrasive materials are utilized to result in kerf losses ranging from .0055" to .017" per wafer. Typical thickness tolerances are ±.002" and tapering is generally held to between .0005 " and .001" per inch of cut depth.

The reduced sub-surface damage and improved surface finish (typically 15 micron RMS) of wafers produced by MBS have proven advantageous in our production of optical parts. Traditional optical production technique has been to wafer materials as much as one-eighth inch greater than desired finished thickness on conventional fixed diamond cut-off equipment. The parts are then finished via a series of blocking and successively finer grinding and polishing operations. Use of MBS for wafering allows slicing much closer to finished thickness and elimination of the cost and handling losses associated with the several intermediate processing steps. In some cases, MBS wafered materials cam immediately enter the final polishing operation. In addition, the improved materials utilization becomes significant because many optical materials are extremely expensive.

Because the workpiece is mounted to some type of fixture, which is in turn affixed to the chuck of the MBS saw, critical orientation of the workpiece can be accomplished away from the saw and maintained through the use of precision mechanical transfer devices. In quartz processing, the major faces of a wafer must be held to specific angular orientations with respect to various crystallographic planes. In some cases the tolerance on this specification can be as small as plus or minus 15 seconds of arc. Typically the MBS process can yield 100% of product within a ±3 arc-minute tolerance and better than 90% within ±2 arc-minute tolerance.

WAFERING OF SILICON FOR SOLAR CELLS - THE JPL LOW-COST SOLAR ARRAY PROJECT

P. R. Hoffman Company is currently under contract to Jet Propulsion Laboratory in support of the Low-cost Solar Array Project. We are to provide testing and development which will result in optimization of both the MBS process and the design of the MBS saw. The goals of this project will not be realized without vast improvement in the state-of-the-art MBS technology.

In the past, solution of technological problems in the production environment has been accomplished empirically. Some attempts have been made to develop mathematical models of the various micro-systems of the process in an effort to identify a practical solution to the various problems involved in successfully producing the large diameter, extremely thin silicon wafers dictated by the project goals. In many instances the theory thus developed has hot been supported by production test results. The ability to wafer 6 inch diameter ingots at 25 wafers per centimeter of ingot length is essentially a problem requiring improvements in machine design and process control. The foregoing discussion has indicated where these improvements must be effected.

The second area of concern, and certainly not secondary in importance, is the over-all reduction of process costs. Major improvements must be made in the process cutting rate and the utilization of consumable materials. Significant increases in cutting rate will result in reduced capital investment due to the reduction of the number of machines, and therefore floor space, required to produce a unit area of silicon "sheet" material. Additionally, labor costs would be somewhat reduced, power consumption would be lessened, and all costs generally related to the physical size of the production facility would be lowered.

The cutting rate is, of course, affected by many dependent and independent variables of the process. The testing being conducted by P. R. Hoffman is intended to establish the effect of these several variables on the cutting rate (and quality of the product), establish the optimized process parameters, and thereby define the design improvements required. As an example, it is known that higher relative blade speed (oscillation) results in improved cutting rates. However, maximum speed is limited by the mass of the moving saw components and various constraints of the drive systems. This identification of optimum operating speed will result in definition of necessary design improvements.

Much of our research effort will be directed toward identification of less costly consumable materials and the extension of their useful life. Currently, blades can be used for only one wafering run through a 4 inch diameter ingot and the abrasive slurry has a maximum life of two wafering runs at best. We are attempting to identify less expensive blade materials and/or materials which will not wear as readily due to the abrasion which exists as the basis of this process. Research of methods to reclaim vehicle and abrasive material is currently under way. Future research will include attempts to use water as the basic slurry vehicle.

In summary, it is recognized that the current state-of-the-art MBS technology must be significantly improved if the LSA project goals are to be attained. While alternative wafering systems have been developed and vastly improved in recent years, MBS has seen little technological advancement. We at P. R. Hoffman believe that major improvementsare not impossible. Although MBS will never be the answer to every wafering requirement, we are confident that economical production of wafers to LSA project specifications will be achieved in the not-too distant future.