Increasing demands for quality shear cut bars have resulted in an evolution in the design and maintenance of shear knives. In addition to proper material and heat treatment, pass geometry and dimensional tolerances are critical to performance. It is essential to have perfect alignment between the upper and lower knives.

Optimizing performance of bar mill shear knives

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THE design, set-up and maintenance of shear knives used in cut to length cold shears are the focus of this article. Although the examples and illustrations concentrate on round bars, the principles involved pertain to shearing squares, angles, channels and other structural shapes. Knives play a vital role in determining the quality of shear cuts. However, the knives are only one part of the shearing system. In addition to the knives, the system consists of the following:

- Shear, including associated items such as hold-downs, knife seats and knife bolts.
- Knife set-up and changing practices.
- Operating parameters such as rolling tolerances and temperature at shearing.
- Knife design.
- Knife reconditioning procedures, including shimming practice.

The quality of shear cuts depends on each of these components. If any of these interdependent factors is not optimized, the overall quality of the shear cuts deteriorates.

Shearing principles

Shearing may be considered as a controlled break or fracture whereby the mechanical or hydraulic force of the shear is transmitted via the knives into the material being sheared. In crystalline structures such as steel, a fracture occurs after a certain amount of elastic and plastic deformation takes place. The direction of this fracture is at a small angle from the direction of the knife travel and is the result of portions of the crystalline grains slipping past each other. Therefore, the direction along which the fracture travels is known as a slip plane. An ideal shear cut occurs when the fracture generated by the upper knife exactly meets the fracture from the lower knife. For this to occur, the separation, generally known as the gap or horizontal clearance between the upper and lower knives must be precise.

The effects of ideal, too-tight and too-open gaps are illustrated in Fig. 1. The end view of a round bar sheared with an ideal gap shows a distinctly smooth knife penetration area and a continuous fracture plane with minimal distortion and burr (Fig. 1a). Such a cut requires the least amount of force since it occurs along the line of natural weakness of the steel—the slip plane.

The end of a round bar sheared with too little gap shows the effect of the upper and lower fractures forming a ledge that is sheared off as the upper knife continues its downward path (Fig. 1b). Shavings accumulated in the shear bed are indicative of tight gaps. This ledge could also be peeled back, forming a burr. The most distinctive feature in a bar sheared with too little clearance is the formation of a secondary shearing zone near the center of the cut end. Unlike the ideal shear cut (Fig. 1a), which shows a distinct nick and break effect, there is a burnished area at the center of the shear cut with a gap that is too tight (Fig. 1b) that results from the initially formed ledge being sheared a second time.

The worst shear cuts are typically the result of too much knife clearance. Both the amount of plastic deformation and the required shearing force increase, causing a distorted, jagged cut (Fig. 1c).

When worn knives are used (Fig. 2), the resultant shear cut is similar to the cut generated by too much gap. Instead of the fracture beginning at the square-cornered edge, as with sharp knives, it starts at a point away from the face and toward the center of the knife. In contrast to being directed specifically along the slip plane, the shearing force is distributed along the radiused edge, producing stress risers. Consequently, areas of the bar are torn rather than sheared.

The adverse effects of using worn knives are not limited to poor shear cuts. Since the required shearing force increases as knives become worn, there is more load on the knives and on the component parts of the shear such as the gibs, bearings and knife seats. The increased load on the shear components results in accelerated wear, misalignment and more frequent shear rebuilding. This overload makes the knives much more susceptible to chipping and, possibly, breaking since the design limitations of the knife could be exceeded. This is especially true when the work-hardening phenomenon is considered. The tool steel knife undergoes strain hardening, resulting from the shearing force being absorbed by the knife. The amount of structural change at the cutting edge surface of the knife is directly related to the required shearing force. As knives continue to wear, additional strain-hardening occurs, increasing the probability of knife failure. Recognition of this work-hardening effect is critical when the method of sharpening knives (discussed subsequently) is considered.

Optimum knife gap is a function of material cross-section, tensile strength and temperature at shearing; all of which determine the amount of knife penetration (plastic deformation) that takes place before fracturing occurs. The ideal gap for a particular bar can only be determined by experimentation. Given a well-maintained shear with little or no horizontal knife separation during shearing, a gap of 1½ to 2% of the bar diameter for low alloy mild steel is a good starting point (0.015 to 0.020 in. for 1-in. dia bar). Because of deflection in the shear and the use of less than perfectly sharp knives, a more practical gap may be 1% of the bar diameter. Normally, higher strength alloy bars sheared at the same temperature as lower strength alloy bars require more clearance since the knife penetration is less.

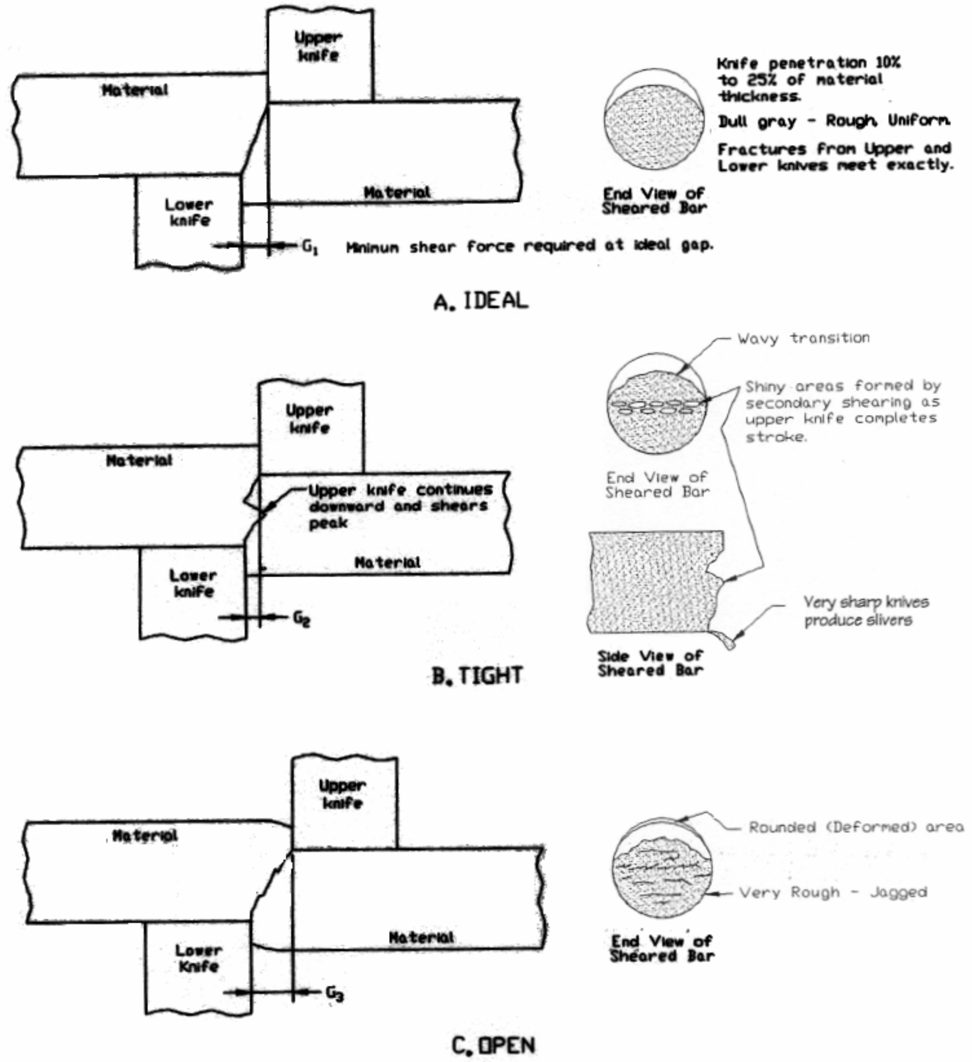


Fig. 1 — Effect of knife gap on shear cut: a. Ideal; b. Too tight; c. Too open.

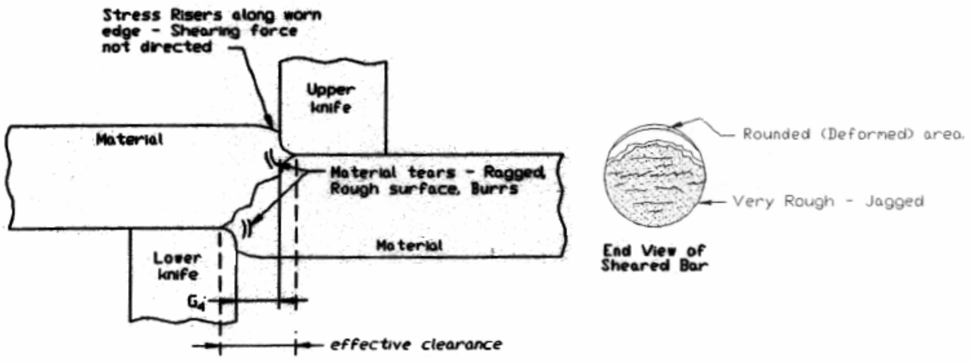


Fig. 2 — Effect of dull or worn knives.

However, given the practice of shearing higher strength material at elevated temperatures, it may not be necessary to increase the gap. Since an ideal knife gap minimizes the required power, a load meter or force gage at the shear can be an excellent tool for establishing horizontal knife clearances.

Product mix constraints and other variables in the rolling process, make it impractical to achieve an ideal gap at all times. However, a knowledge of these shearing principles may assist in establishing procedures which would reduce problems such as bar distortion, bar cracking and excessive knife wear.

The normal method for determining the existing gap between knives is the use of feeler gages. Special micrometers or dial indicators are available for precise measurement. When determining the proper gap, consideration must be given to the fact that the measurements are taken in a static or unloaded condition. Most likely, the gap under load will be greater.

Knife design

The elements of knife design can be categorized as:

- Knife material (tool steel).
- Heat treatment (working hardness).
- Rake.
- Pass design.
- Dimensional tolerances.

The most common material used for manufacturing cold shear bar mill knives is an S series tool steel, heat treated from 50 to 56 Rockwell C scale. The hardness is adjusted according to the size and strength of the steel being sheared. Both S-7 and S-5 tool steel are used. The hardness of knives used for shearing larger sections or higher strength steel are normally a lower (50 to 52 Rockwell C). S-5 tool steel is generally used when additional shock resistance is required because of its lower chromium and carbon content.

Two basic rake designs are currently used for shearing multiple bars: single and double rake (Fig. 3). A zero-rake design is not common. It is used, however, for shearing one bar at a time, as in test shears. Knives with a single-rake design have an advantage over knives without a rake in that considerably less force is required to shear multiple bars, because the bars are sheared progressively along the length of the knife. Since only a few bars are engaged in the shear at any one time, the required power capacity of the shear is minimized. One disadvantage is that pass alignment requires that only one edge of the upper knife can be used. In addition, an inherent problem with the single-rake design is an unbalanced load which travels along the length of the knife during the progressive cut. This unbalanced load induces a twisting action, that precipitates localized wear in the shear components, particularly in the gibs and knife seat.

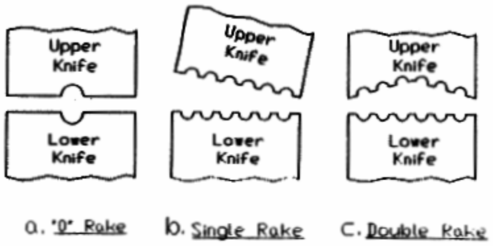


Fig. 3 — Knife design: a. Zero rake; b. Single rake; c. Double rake.

It is common, especially in older shears, for the upper knife seat to become out of parallel with the lower knife seat with the result that the gap will vary along the length of the knives and, therefore, the quality of the shear cuts will vary. To temporarily correct this non-parallel condition, partial shims are used behind the knives. Such a practice may cause pass misalignment and increased loads on the knives and knife bolts. A better temporary solution is the use of a solid, full-length tapered liner to bring the knives back into parallel (Fig. 4). This full-length liner completely supports the knife. The ultimate solution is to rebuild the shear.

Similar to a single-rake design, a double-rake configuration (Fig. 3) minimizes the required shearing force. In addition, it reduces the unbalanced load distribution associated with the single-rake design. The shearing occurs in both directions along the length of knives starting at each end and progressing toward the center. Consequently, the force is more equally distributed and localized wear is reduced. Both edges of the upper knife can be used.

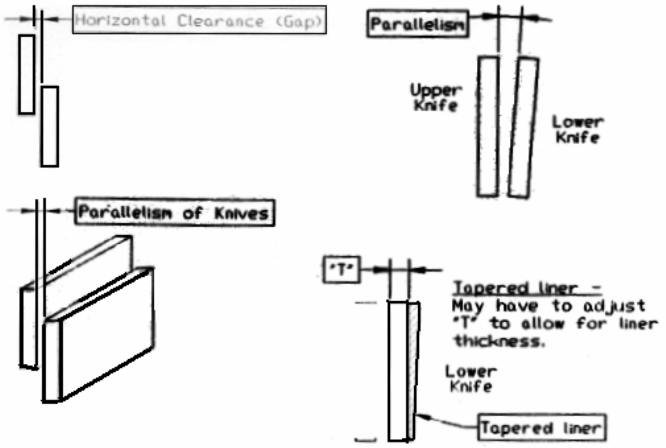


Fig. 4 — Temporary solution to out of parallel knives: tapered liner.

When using single-rake knives, consideration must be given to the position of the passes. The pass relationship between the lower knife and upper single-rake knife is shown in Fig. 5. For perfect alignment to occur, the lineal spacing of the passes in the upper knife must be slightly greater than the lineal spacing of the lower knife. Furthermore, the centerlines of the passes must be normal to the passline instead of normal to the top of the knife. In the example shown, a rake of $2\frac{1}{2}$° results in a spacing differential rate of 0.001 in./in. Therefore, if the spacing between the first and last pass of the lower knife is 40.000

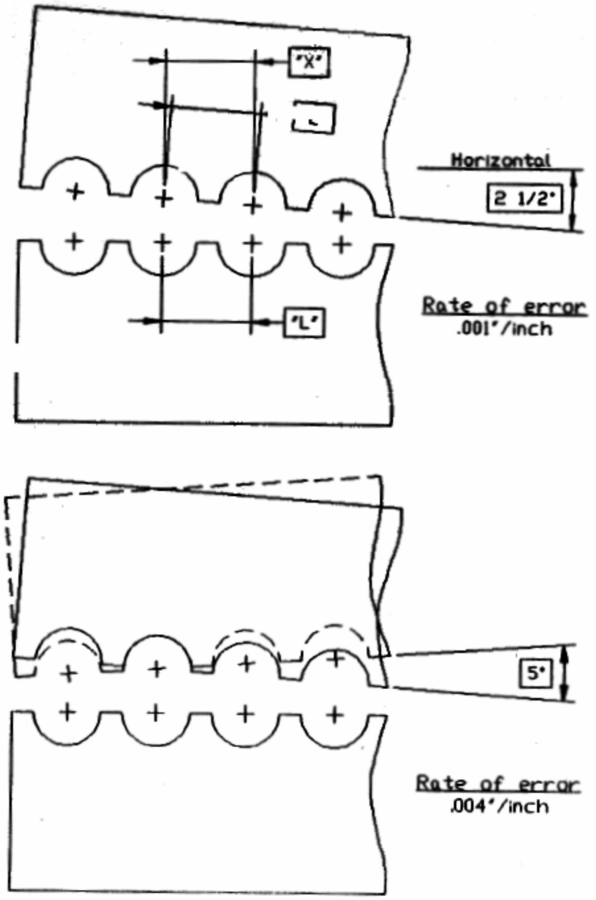


Fig. 5 — Pass relationship is between lower and upper single-rake knife.

in., the corresponding spacing in the upper knife would have to be 40.040 in. If the upper knife is manufactured in such a manner, it is essentially a one-edge knife. This is because rotating the knife 180° to use the second edge would cause a gross pass misalignment. In this example, the misalignment would be at the rate of 0.005 in./in. Consequently, for every lower knife, two upper knives are required. In addition, the upper illustration in Fig. 5 shows that if the knives are ground with the centerline of the passes normal to the top of the knife there is slight pass misalignment. The lower illustration shows that if the knives are ground with the centerline of the passes normal to the rake angle, only one edge is in alignment.

Single-rake shears with relatively short knives (under 30 in.) can produce acceptable results by the use of upper and lower knives having identical pass spacing. Since there is less distance between passes, the misalignment of the lower knife with the upper knife in the rake position is minimized. As a precaution against marking the bars, a pass design that incorporates a 15 to 30° tangent (flare) of the radius should be used. This type of the pass design is illustrated in Fig. 6 with the knives shown in position to shear. The centerline of the upper and lower passes must coincide. The radius, R, is equal to one-half the diameter of the largest bar being sheared plus the desired clearance to account for rolling tolerances and increase in size due to elevated temperature.

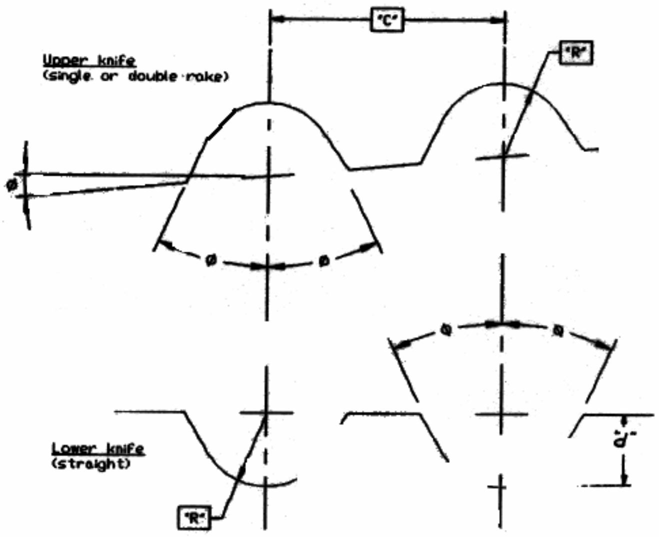


Fig. 6 — Pass design incorporating radius flare to avoid marking bars.

Some newer shears incorporate the accuracy of the double-rake design with the rigidity of a die-set concept. The upper and lower knife seat housings are connected by linear bearings. This arrangement insures that the vertical travel of the upper knife is in a parallel plane with the lower knife. As a result, constant knife gaps are maintained. Another major advantage of this design is that the majority of the shearing force is absorbed by these linear bearings, not by the shear components.

Pass design

There are two main principles to consider in determining pass design:

- The more closely the pass geometry conforms to the geometry of the bar being sheared, the better the cut will be.
- If the pass geometry is designed to closely match that of the bar, the dimensional tolerances of the shear knives must be small.

Pass design is determined by the importance of a quality shear cut. When a high quality shear cut is not required, a pass radius that accommodates a size range of 0.250 in. may be acceptable. However, when quality is critical, a different knife may be required for every 0.015-in. change in diameter. When designing an ideal pass, the following information must be known:

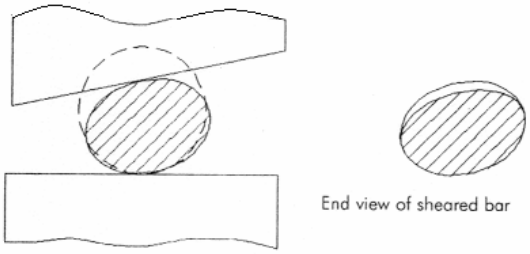
- Size of bar and plus side of rolling tolerance.
- Shearing temperature to determine size of bar when being sheared.
- Whether shear is single or double rake.
- Whether or not dedicated upper and lower knives are used.

As indicated previously, the radius of the pass must be equal to the sum of the radius of the bar at shearing temperature and the size tolerance (Fig. 6).

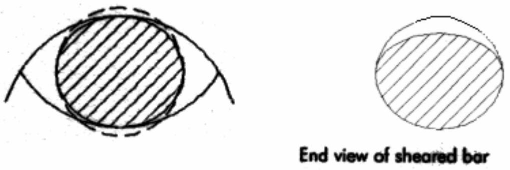
For example, a 1.000-in. bar having a rolling tolerance of +0.010 in. has a maximum diameter of 1.015 in. when sheared at 800°F. The minimum pass radius should be 0.508 in. A manufacturing tolerance of +0.005 in. –0.000 in. is appropriate.

Knife penetration is normally within 25% of the bar diameter. This means that the pass depth (d in Fig. 6) can be less than the bar radius.

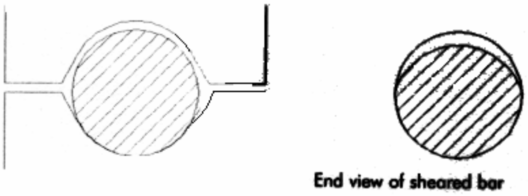
However, as the shearing temperature increases, knife penetration also increases, resulting in a greater amount of plastic deformation. This deformation forces the bar to take the shape of the pass. If the pass radius does not fully support the knife through the cut, a squashing effect takes place (Fig. 7). Flat areas corresponding to the flare of the pass will appear. To avoid such problems, the pass depth must be equal to the bar radius and the tangential flare



a. Flat Knife.



b. Pass having radius much larger than bar.



c. Pass having radius only slightly larger than bar radius.

Fig. 7 — Effect of pass profile on sheared cut: a. Flat knife; b. Pass radius considerably larger than bar radius; c. Pass radius slightly larger than bar radius.

must be minimized. Such a design increases the necessity of a near perfect alignment between the upper and lower knife passes. Even a slight inaccuracy may cause the knives to mark the bars. (The amount of plastic deformation will vary with the alloy and temperature at shearing.)

Knife bolts

An area of importance, that is sometimes overlooked, is the use of proper knife bolts. Any deformation in the bolt, nut or washers can result in poor knife seating and movement of the knife during the shearing process. Such movement precipitates poor shear cuts and knife damage. The specification of the bolts, nuts and washers should be of Grade 8 quality, 4140 steel, heat treated to 28 to 32 Rockwell C.

The accuracy of the bolt head is important since the holding force is predicated on the fit between the bolt head and the counter sink of the bolt hole. Since the heads of forged lug bolts are not perfectly round, the amount of bearing surface the bolt head makes with the countersunk hole in the knife is limited. Replacing the lug bolt with bolts having a machined, perfectly round head may reduce the risk of knives becoming loose.

Knife sharpening

The benefits gained from establishing standardized knife setup procedures can be derived only when the knives are consistently sharp and dimensionally accurate. It is essential, therefore, that the reconditioning procedure used restores the knives to their original accuracy and metallurgical properties. There are three possible methods of sharpening the knives:

- Grinding flat surfaces only.
- Grinding passes only.
- Grinding both flat surfaces and passes.

The wear pattern within the pass of a worn knife is depicted in Fig. 8. (For discussion purposes, the wear pattern has been exaggerated.) The wear tapers from the center to the face of the knife. Consequently, reconditioning knives by removing stock from the flat surfaces only will not achieve a truly sharp (90°) cutting edge (Fig. 8, view a). To generate a reasonably sharp knife by flat grinding only, a large amount of stock must be removed, thereby shortening knife life. Furthermore, flat grinding will not totally remove the work-hardened zone, which increases the danger of knife failure.

Grinding the individual passes to a depth below the wear and work-hardened zone restores the knife's original pass geometry and physical properties (Fig. 8, view b). The pass grinding procedure must guarantee that the individual pass geometry is accurate and that the pass alignment between the upper and lower knives is precise. Consistent pass depths are especially important, particularly in the lower knife. These uniform depths allow an accurate passline (bottom of knife to the bottom of pass) dimension to be maintained. This dimension must be precise to avoid bending or marking of the bar.

Reconditioning by grinding the passes only is considerably superior to grinding the flats only. However, since the flat surfaces of the knives become worn by the abrasive action of the bar, it is beneficial to remove some stock from the flats. Additional benefits of removing at least some stock from the flat surfaces are:

- Removal of any knife distortion.
- Elimination of material pick-up, which could interfere with proper knife seating.
- Reduction of required stock removal from the passes.

When the knives are pass ground only, side shims are not required. This advantage must be weighed against the advantages of side grinding.

The reconditioning procedure should include a standard for determining when the knives should be sharpened. Knives should be sharpened on a planned basis, predicated on the number of cuts and/or tonnage sheared. It is false economy to delay sharpening beyond this point.

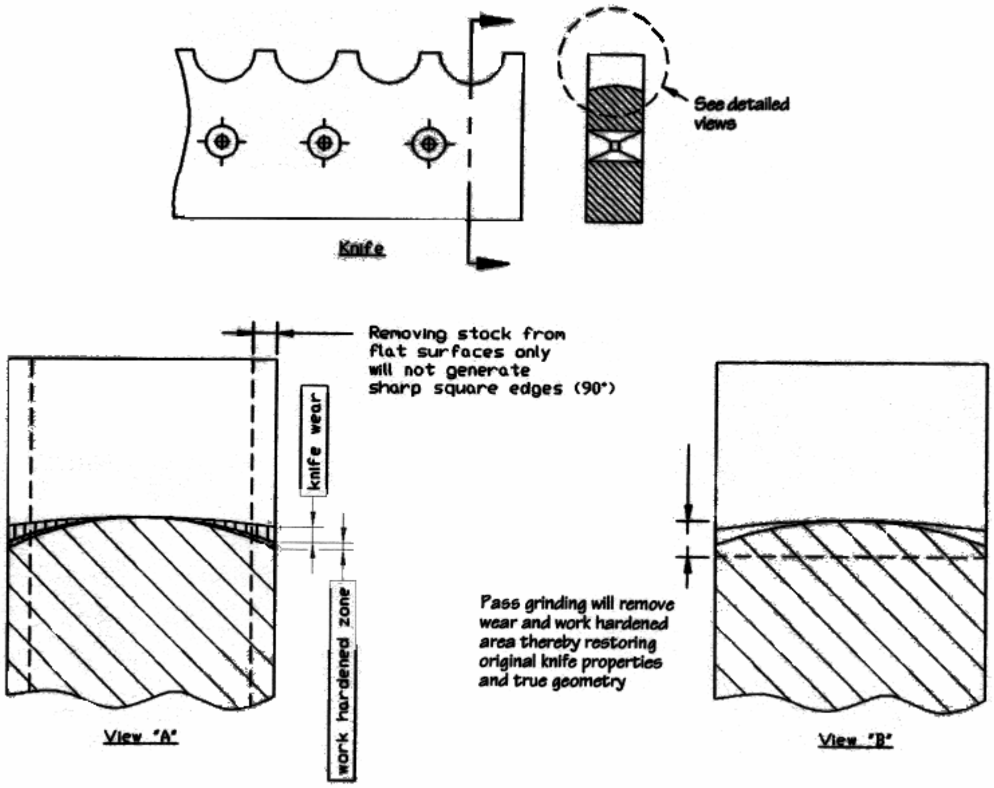
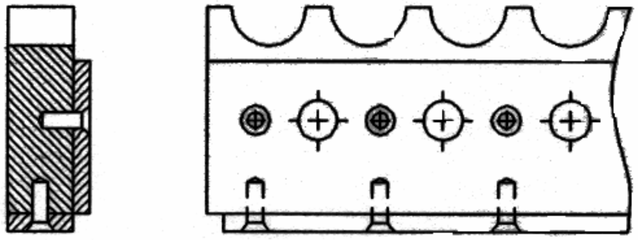


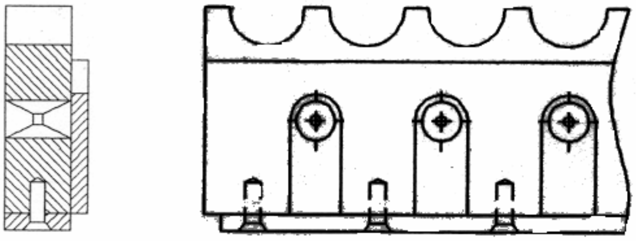
Fig. 8 — Knife sharpening considerations.

Some of the adverse effects of using worn knives have already been discussed, such as poor shear cuts and overloading of the shear components. In addition, postponing sharpening accelerates the deterioration of the knife and increases the amount of stock removal required to generate sharp edges. The rate at which the knife wears is not a straight-line function; it increases with the total amount of wear. Therefore, the longer the knife is used, the more rapidly it wears. In fact, the last 10% of usage could be responsible for the majority of wear.

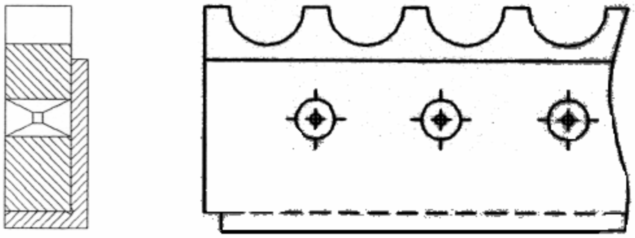
An essential part of the reconditioning procedure is shimming the knives to maintain original dimensions. Shimming methods are illustrated in Fig. 9 with the advantages and disadvantages of each method summarized in Table I. The bolted-on shims shown in Method 1 insure the highest accuracy because the shims can be ground while bolted. However, it is necessary to remove the shims and then reattach the side shim to use the second edge. For this reason, Method 1 may not be practical.



1. Bolted-on shims - thickness & height (Pass line)



2. Bolted height shims - Slotted side shims



3. "L" Shaped Liners - Held in by knife bolts

Fig. 9 — Methods of shimming reconditioned knives: Method 1—Bolted-on shims; Method 2—Bolted height shims; and Method 3—L-shaped liners.

TABLE I Methods of shimming reconditioned knives

Method	Advantages	Disadvantages
Bolted-on shims - thickness and length	Very accurate - shims ground white bolted	Necessary to remove and reattach shims for second edge
Bolted height shims - slotted side shims	Accurate height shim, shim stays with knife	Slotted shims must be maintained - must be clean and free from burrs
Thickness	Slotted thickness shim allows adjustment without removing knife bolts	
L-shaped liners - held by knife bolts	One-piece design eliminates need to bolt height shims	More expensive Unique to one knife Careful storage to avoid damage

Method 2 is more manageable. The height shim is bolted to the bottom of the knife and ground in place. This allows for an accurate passline dimension. The side shims have slotted bolt holes, allowing them to be changed without removing the knife bolts. Method 3 can be employed to shim both the height and thickness by the use of L-shaped liners. This method is cost effective only if the knives are ground to incremental sizes, enabling the liners to be reused. The quality of the shims ultimately determines the overall accuracy of the knife setup. They must be clean, straight and free of burrs.

Conclusion

The individual items discussed can be considered units within a system. When each unit functions at near-optimum level, it supports the other units. The natural consequence is good overall performance, including good shear cuts.

Summary

The increasing demand for quality shear cut bars has resulted in an evolution in the design and maintenance of shear knives. In addition to proper material and heat treatment, pass geometry and dimensional tolerances are critical to performance. It is essential to have perfect alignment between the upper and lower knives.

Knives are only one part of a shearing system. Predictable, consistently good quality cuts can only be achieved when all the component parts of the system are at or near optimum. Other component parts of the system are:

- The shear and associated items such as hold-downs and knife bolts.
- Knife set-up—parallelism and horizontal clearance.
- Knife reconditioning—proper grinding techniques.

The principles of shearing involving theoretical ideal horizontal clearance (gap) and practical limitations in achieving ideal gap are discussed. ▲

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