

HARD TURNING AND THE MACHINE TOOL

Daniel P. Soroka, Hardinge Inc.

One Hardinge Dr.

Elmira, NY 14902

607 378-4423

dsoroka@hardinge.com

ABSTRACT

Producers of machined components and manufactured goods are continually challenged to reduce cost, improve quality and minimize setup times in order to remain competitive. Frequently the answer is found with new technology solutions. Such is the case with grinding where the traditional operations involve expensive machinery and generally have long manufacturing cycles, costly support equipment, and lengthy setup times. The newer solution is a hard turning process, which is best performed with appropriately configured turning centers or lathes. This paper describes how the machine tool characteristics such as dynamic stiffness relate to the total operation in terms of part quality, tool life and the economics of the application. Current and future development activities are targeted toward improvements in the machine tool dynamic stiffness as well as in the process area for methods to control white layer formation.

HARD TURNING, A VIABLE PROCESS DESCRIBED

Manufacturers around the world constantly strive for lower cost solutions in order to maintain their competitiveness, on machined components and manufactured goods. Globally, part quality has been found to be at acceptable levels and it continues to improve, while the pressure for part piece cost is enormous and is constantly being influenced downward by competition and buyer strategies. The trend is toward higher quality, lower cost and smaller batch sizes. In order to compete against producing countries with low wage structures, it is necessary to seek out appropriate new technological solutions that can help to level the business playing field.

Technology has played an enormous role in advancing the metal working industry and creating opportunities to reduce costs and improve quality. Consider the role technology has played in transforming routine metal cutting operations. At one time machining was very much an operator dependent, skill critical process. Today, CNC machine tools, which operate with mature technology and provide both consistency and reliability, have now become the biggest contributor to part quality and cost. Technology-based tools such as 3-D CAD systems, computer programming, simulation packages and of course the CNC machine tool, are now commonplace in many shops and in most countries of the world. A rapid adoption of these newer and more cost effective manufacturing techniques will be constantly required if manufacturing operations are to remain competitive.

In a much smaller way, but no less significant, we begin to see a technology evolution occurring in the area of hard turning. Hard turning is defined as the process of single point cutting of part pieces that have hardness values over 45 RC but more typically are in the 58-

68 RC range [2]. The cutting tools of choice are typically Cubic Boron Nitride (CBN), Ceramic and sometimes Cermet. The tooling choice will need to be matched to the application, desired production rates and the operating cost goals. CBN is the most dominant choice for the more demanding applications of size and finish and particularly those components which had been transitioned from grinding. In 2001 the sales of CBN tools exceeded \$250 million, providing an idea as to the somewhat broad use of this technology [2]. Other applications which have broader tolerance ranges, typically in the area of .002" on diameter, might be better candidates for Ceramic tools which have a cost structure similar to carbide. In any case, the better tool performance will be seen with systems that provide negative rake angles since they have a more robust cutting edge but do place a higher demand on the type of machine tool that can be used and its' inherent stiffness.

It is commonly known that carbide is available in a wide range of grades and coatings and which are intended to be best matched to the application. In a similar way CBN cutting tools are available in several grades and likewise should be properly chosen to the requirements. As an example, a low content CBN insert will not perform well in an interrupted cutting application because it lacks the necessary toughness. Generally, high content CBN inserts have higher toughness whereas low content inserts provide longer tool life in straight turning applications.

Hard turning does provide an alternative for those applications that do not require the high end processing capability of a grinder, or for pre-grind roughing operations. Clearly, for many applications involving very close tolerance work, compliant work-pieces that are prone to distortion or unusual materials, grinding will still remain the process of choice. More specifically, hard turning does not eliminate the need for grinding but can relieve the production burden on the more expensive grinders for the properly chosen application. In terms of performance a typical a hard turned part which is processed on a correctly configured machine, can have surface finishes below .0003 mm, roundness values of .00025 mm and size control as good as .005 mm.

The range of hard turned applications will vary based upon the part requirements, tolerance levels, surface finish and very importantly the machine tool. Not all machines are suitable for hard turning operations, and the differences will be addressed in a later section of this paper. In terms of the process routing, hard turning may be used in a pre-grind operation or in sequences that are followed by superfinishing. It is very common, however that the hard turned surface completes the part since the achievable accuracy and surface finish approaches or equals that of the grinding process. At whatever point in a product manufacture that hard turning is incorporated, the user is very likely to benefit from lower costs and increased through-

puts which can range from 4 to 6 times the output of a comparable grinding operation.



Figure # 1; Hard Turning on a Hardinge Quest lathe

In Fig. #1, a RC 62 hard part is being machined without coolant, and it is clear that the chip temperatures are extremely high, and in fact the cutting zone in dry operations, is normally in the range of 925 degrees Celsius. The localized heating that occurs at the tool tip tends to aid in the cutting action, since the heat generated at the tool tip begins to anneal and soften the material just ahead of the tool, making it easier to shear. A measurement of the hardness of the cut chips will frequently show values, which are below one-half of the hardness of the base material, thereby demonstrating this scenario. This will also explain why faster speeds have been shown to actually improve tool life in some applications since the material being cut has been annealed to lower hardness levels. Overall this mechanism which seems to work in favor of the process does not come without a price. Hard turned surfaces frequently experience white layer formation, which according to Griffiths [4] can be caused by either 1) severe plastic deformation that causes rapid grain refinement or 2) phase transformations as a result of rapid heating and quenching. Additional information about white layer is covered in a later section of this paper, but fundamentally white layer is not desirable in products which have high contact stresses and where fatigue failures can occur.

As previously stated the high tool tip temperature tends to anneal the pre-cut material, however it is important to note that the vast majority of the heat that is generated from the hard turning process is actually removed in the chip. For typical dry cut finishing operations where the total metal removed is minimal and depth of cuts are in the order of .25mm, the part can be carefully handled after the process is completed. Applications where the total metal removal is greater than this will logically be at higher temperatures and care should be taken when handling these parts. There are five important items to consider when choosing to process parts dry. First, the workpiece temperature is somewhat elevated and this should be considered when gaging immediately after cutting. Secondly, dry cutting will have higher temperatures at the tool and a somewhat lower tool life as compared to cutting with coolant. Third, the surface finish for dry cut operations is seldom as good as can be achieved with coolant. Fourth, consideration should be given to the high temperature chips, which must be restricted from operator exposure, and prevented from contacting lubricants that might be present on the machine. Lastly, the tool material needs to be correctly chosen. Such is the case with Ceramics which are prone to early failure under thermal shock conditions, so they would not be good candidates for coolant cutting, and should almost always be operated dry. One effective alternative for dry cutting is a properly configured air jet which is highly recommended for both cooling and chip control. Care should be taken to prevent the chip from re-entering the cut region and passing between the tool and the finished workpiece. This is especially true of facing operations where the chip can easily be re-cut. Surface finish flaws can generally

be traced to these conditions and can routinely be avoided by a properly set-up air jet.

The current tooling technology allows the user to be able to choose between "wet or dry" operations. Wet operations refer to processes under flood or high-pressure with a water-soluble coolant. The decision to produce under wet or dry conditions is normally made at the individual factory level. Some facilities have a local philosophy or mandate regarding the preference to operate one way or the other and fortunately, either forms of hard turning can be accommodated. There are several key items when choosing to operate wet and the first of these is the type of fluid to be used. Generally, straight oils should be avoided because of the inherent fire hazard. This is particularly true if during a cut the coolant flow is disrupted and the unquenched, high temperature chips contact the oil. Under these conditions, oils with a low flash point could start and sustain a fire.

Another point for wet operations is the importance to properly direct the coolant flow by applying fluid to both the top and the bottom of the tool tip simultaneously. Generated chip strings will frequently shield the coolant from the tool until the chip breaks away. The result is thermal shock and a process of degradation of the cutting edge. Anticipate this when establishing the coolant nozzle locations from a slight sideward vantage point. High-pressure coolant at pressures of approximately 68-95 atmospheres seems to be beneficial in keeping the chips small and manageable and in making the overall process more robust. As previously stated, the shorter chip results in a reduced amount of coolant blockage and less thermal shock to the cutting edge. Another variable in coolant cutting operations that can easily sabotage a fine-tuned process is an improper coolant mixture. Concentration, cleanliness and pH levels cannot be ignored for a proper application. The one possible exception to coolant cutting is on interrupted surfaces, which seem to perform better in a dry environment. Logically, this is due to the higher degree of thermal shock caused during the interruption when the coolant has a better access to the tool tip and then immediately is followed by a re-entry into the workpiece and the severe temperatures.

If one were to list the current applications of hard turning it would certainly be a voluminous document. On a daily basis, parts are being hard turned in the following industry segments; automotive, bearing, marine, punch and die, mold, hydraulics and pneumatics, machine tool and aerospace. While these industries are representative, this list is certainly not conclusive and new applications and industry segments are constantly being added.

Material types for hard turning applications are as varied as the part forms, and can also be indicative of a rather long list. Commonly processed materials would include all manners of hardened steel alloys such as bearing steels, hot and cold-work tool steels, high-speed steels, die steels and case hardened steels. Inconel, Hastelloy, Stellite and carburized and nitrided irons along with some coatings like high chrome can also be serious candidates for this process.

In Fig. #2 is shown a gear pump shaft from the fluids industry. On this particular part the material is hardened to RC 60-62 and the machined surfaces are close tolerance bearing journals and seal surfaces. Other operations performed on this part include the interrupted cuts of both the gear teeth crests and the gear faces.

Figure # 2 Gear Pump Shaft



Several variables that can dramatically affect a well-tuned hard turning application are a variation in the material hardness and case depth. When the hardness is controlled to less than a 2-point spread on the Rockwell C scale, the process is better optimized for throughput and tool life. The surface finish will also be better with the closer controlled hardness point spread and will require fewer attempts to adjust machining parameters as the finish begins to degrade.

As the success and confidence grows with each hard turning application, new challenges are constantly being considered. However, for every successful application that can be described, there are many others that are not discussed for fear that a real competitive advantage may be disclosed.

Now that the process and the application have been described in some detail, it is appropriate to summarize some of the advantages of the hard turning technology;

- The lathe offers the versatility to "Soft Turn" and Hard Turn on the same machine tool. A single machine performing the work of two has the added benefits of freeing up vital floor space and being a much lower capital investment.
- Metal removal rates with hard turning are 4 to 6 times' greater than equivalent grinding operations.
- Single-point turning of complex contours is routine on a lathe, without the need for costly form wheels.
- Multiple operations can be turned with a single set-up, resulting in less part handling and a reduced opportunity for part damage.
- Hard turning can achieve low micro-inch finishes. Surface finishes ranging from .0001 mm to .0004 mm are very common.
- The hard turn lathe is generally more adaptable as configuration changes are introduced. Lathes are also able to process small batch sizes and complex shapes.
- Environmentally, the hard turned chips are less costly to dispose of than grinding swarf. Dry cut parts without coolant contamination are even more economical to dispose of.
- Tooling inventory is low compared to grinding wheels. Moreover, the CBN inserts will generally work in the existing tool holders used for multitudes of operations.

In the area of machine tool development it is becoming more common to see equipment that supports multiple processes and is designed or targeted for greater versatility and utilization. Such is the case with hard turning and it is seen as a growing trend in plant operational strategies and lean manufacturing. The need to find ways for a greater utility from a machine investment will remain a driving force in the advancements of hard turning.

THE MACHINE TOOL AND TECHNOLOGY SOLUTIONS

Many of today's modern machine shops are beginning to realize the benefits of hard turning, and for some it is becoming a standard, qualified process. As the technology of hard turning advances it is

becoming obvious that the highly successful applications are those that are run on machines with key performance attributes. Hard turning results are as varied as the machines that are used but the greatest success are achieved from machine tools that address several key issues in the design and construction.

The Importance of Dynamic Stiffness

In terms of ranking attributes for machines based upon importance, the top of the list should be equipment that operates with low levels of

vibration over a wide frequency range. This is achieved by designs with a high dynamic stiffness and which are operated with a low-level of ambient vibration. The dynamic stiffness of a machine is a measure of the ratio of the applied force to the displacement, occurring at the frequency of the exciting force. Typically, the dynamic stiffness is determined for a range of frequency values, which fall within the operating range of the machine tool. The static stiffness on the other hand is simply the ratio of an applied force to the associated displacement. Typically, the dynamic stiffness of a machine tool will establish the upper boundary in achievable part quality. Surface finish, size control and tool life are all dictated by the dynamic stiffness of a machine tool and this make it a vital machine attribute.

As a rule of thumb the forces involved in hard turning are approximately 1.5 to 2 times those for an equivalent annealed workpiece. While many applications are finishing operations with a small depth of cut, the light cuts do not diminish the important need for a high dynamic stiffness. Machine tool designers have known for many years that there is a practical and economical limit as to how statically stiff a machine structure can be effectively designed and produced. Therefore, once the appropriate level of static stiffness has been achieved, the only remaining opportunity to increase the dynamic stiffness is to add damping. This is achieved by technologies such as composite filled bases and hydrostatic way systems [1,6]. For this reason Hardinge Inc. has traditionally used its proprietary polymer composite (Harcrete) in machine bases. Harcrete has damping characteristics that can be up to 8 times that of cast iron. Depending on the performance and cost requirements, the base can be all composite or a combination of conventional casting with strategically reinforced Harcrete cavities as shown in Fig. # 3. In this case the cavities of polymer concrete are applied in a symmetrical array so as not to dramatically affect the thermal response of the structure.

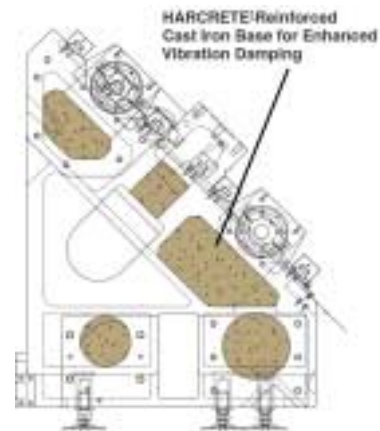


Figure # 3 Machine Base with polymer concrete fill in the shaded areas.

In manufacturing machine tools with high dynamic stiffness, hydrostatic way systems and certain assembly techniques are yet other key technology elements. Machines assembled with such exacting

tolerances that shimming is not required will exhibit high joint contact stiffness. Significant gains are further realized with hydrostatic ways which are non-contact pressurized fluid bearings. The hydrostatic ways use internal lands and small gaps to create pressure by hydraulic resistance. These systems are inherently stiff and have a high load capacity to support the externally applied loads. The fluid film acting in the narrow gap between the block and the rail provides the high levels of damping in the presence of vibration [6]. Such a system is shown in Fig. #4, and will mount in the same space as a conventional linear ball guide shown in Fig. #5. The linear ball guides of Fig. #5 and sometimes roller guides (not shown) have been very popular way systems for machine tools of all sorts. They exhibit low friction and high stiffness and generally do not require wear adjustment. However, in very demanding hard turning applications, the linear ball guides contribute very small levels of damping. These damping levels may not be adequate to achieve the higher levels of part quality and tool life. This is especially true when other damping techniques like composite base elements are absent from the configuration.

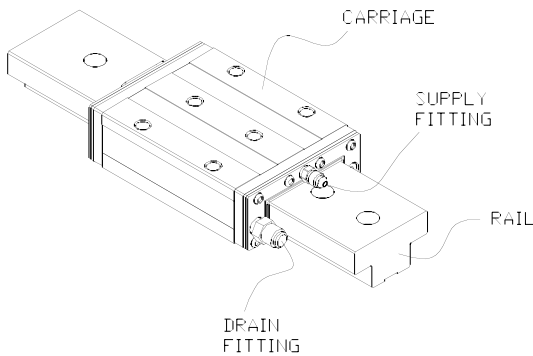


Figure # 4; Hardinge Hydrostatic Guideway, This guide is a non-contact pressurized fluid bearing with recoverable fluid, which will resist linear and moment loads in all directions.

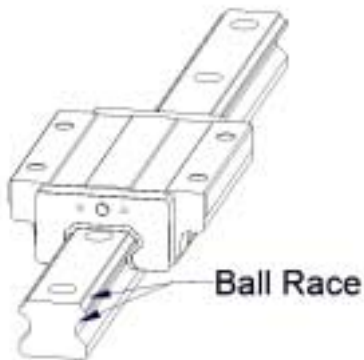


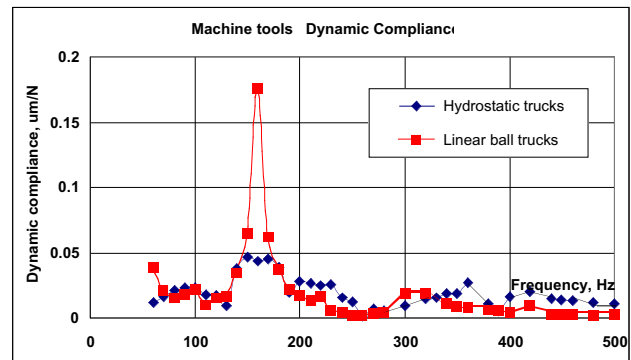
Figure # 5 Linear Ball Guide System, This guide is a re-circulating ball system with ball to race rolling contact. This system will resist linear and moment loads in all directions.

The use of polymer concrete base reinforcements along with the hydrostatic ways is a powerful combination for all turning operations

and especially so for hard turning. Overall, significant improvements in machine dynamic stiffness will result in a dramatic reduction of both the amplitude of vibration, and the time to decay, all while maintaining static stiffness. The real and measurable results are longer tool life, better surface finishes, improved accuracy, increased productivity and higher overall part quality.

In this regard, Hardinge has conducted tests comparing the vibration characteristics of a machine tool with the hydrostatic guides against a machine equipped with linear ball guides [5]. Figure # 6 shows the compliance of the machine structure for both the hydrostatic guides and the linear ball systems. It can be seen that as a result of the damping contribution of the hydrostatics, the dynamic stiffness measured at the tool tip at the natural frequency was increased by a factor of 4.

Figure #6; Dynamic Stiffness Comparisons of Hydrostatic Vs Linear Ball Guides



A 4:1 increase in dynamic stiffness at the natural frequency (159 Hz) will return substantial benefits to the user as will be shown in the following test results. The test piece was made from A-2 tool steel, through hardened to RC 60-62, and of the form as shown in Fig. #7. On the left is the blank part piece with the machined grooves for interrupted cut testing. In the center and right positions are finished pieces. Please note the OD contoured radius, the hard threaded area and the interrupted OD cut. All hard turned operations on this part piece were accomplished with CBN inserts.



Figure #7; A2 tool steel test piece through hardened to RC 62. This test demonstrates hard turning of an interrupted cut, threading and contour machining.

The results of turning this part on the hydrostatic machine were as follows;

- Surface finishes of .00013 to .00015 mm, a 2-fold improvement over the linear ball guide way machine.

- Tool life improvements of 38% greater than the linear ball guide way machine.

Many hard turn operations use CBN inserts, which are available as solid CBN or the more standard form of brazed chips onto pocketed carbide inserts. The brazed chip insert is the most popular choice since the CBN tooling material can be quite expensive, and the solid inserts are obviously much more costly. Operators and technicians that frequently use these tools recognize that CBN does not hold up well in the presence of vibration as some carbide grades might. Therefore machine systems that operate with lower vibration levels can better exploit the capability of the CBN cutting material and expect a longer tool life as demonstrated in the Hardinge tests.

In terms of tooling cost, it can be shown that a typical lathe operating two shifts, five days per week at 80% utilization will consume carbide inserts valued at \$50,000 in a year of production time. This is based upon a 12-station tool plate and a \$20/day insert cost. In other words, with a \$150,000 lathe, three years of consumable costs would equal or exceed the cost of the original machine investment. As will be shown later, technology, which drives tool life improvements, makes a tremendous difference in operating costs. The cost and life of CBN varies greatly but the inserts as a general rule, will cost approximately 3-4 times that of carbide inserts. The life expectation is generally 4 - 20 times that of carbide, for most applications. Therefore on an average basis the ending cost of the CBN may approach that of carbide or might be slightly lower. It is important to note that the longer tool life associated with the CBN is likely to be directly related to the lighter finishing cuts typical of hard turning. There are obviously many variables, but in simple terms with an annual tooling cost of \$50,000 a 38% improvement in tool life as noted in the above test results will represent tool savings of \$19,000 per year. The consumable savings alone will equal the original machine cost in under 8 years.

Motion Capability and Machine Accuracy

The next critical machine attribute is derived from a series of elements, which when linked together represent the motion capability and accuracy of the machine tool. This category would include the combined behavior of the machine resulting from the axes resolution, profile accuracy, control features, error compensation, geometric alignments, lost motions, axis stiffness and the effect of thermal distortions from heat generation of internal and external sources. Individually and in concert these elements can each be rather extensive topics of discussion, and they need to be considered when choosing a machine for hard turning. This attribute will dictate the upper bound for profile and contour accuracy, which as stated previously is a significant advantage of hard turning. Furthermore, with the digital technology associated with modern servo systems, computer optimization can be performed so that the system is “tuned” for the most accurate path control. Axes which are constructed with hydrostatic way systems can better exploit the advantages of system “tuning” since the machine profile control is enhanced by a lower friction level over that, characteristic of ball guide systems.

Since the elements, which affect machine accuracy, are an extensive study, a more straightforward technique for machine selection would be to design a series of tests using machined artifacts and statistically based measurements. The tests should be conducted for the range of anticipated operations and in varying machine thermal conditions. Additionally, the machine may be tested to one of the prevailing commercial standards such as ASME B5.57, which is entitled “Methods for Performance Evaluation of Computer Numerically Controlled Lathes and Turning Centers”.

Spindle Tooling and Tool Holders

There are two other elements not part of the machine tool but are very important to overall success. A hard turn process needs rigid spindle tooling and rigid tool holders. Oftentimes the occurrence of chatter or poor part quality can be directly traced to a lack of stiffness in either of these areas. A common miss-assessment is that the problem is associated with the machine tool when enhancements in the tooling will dramatically improve the process. Oftentimes in hard turning the stiffest tooling approach may be the safest and best performing. Quick change tooling systems at either the spindle or the turret may need to be set aside in favor of the greater stiffness of conventional tooling. Other areas of sensitivity in planning a hard turning application are the tool geometry and the centerline height setting, both of which will influence the cut quality. The orientation of the tools should also be chosen so that the tangential cutting forces are directed into the base of the machine, rather than away from the base. When considering spindle tooling the shorter the distance from the spindle bearings to the cutting location, the better, since the deflection will vary by the cube of the exposed length. When workholding collets are used, the Hardinge design draws the collet into the spindle thereby providing the stiffest workholding arrangement possible, and as shown in Fig. # 8.

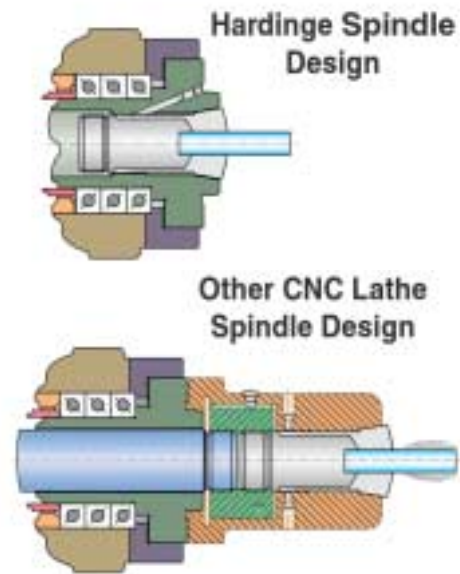


Figure # 8 Draw in collet to maximize stiffness of the workholding system. Note the location of the spindle bearings relative to the workpiece in both cases.

Successful Hard Turning Summarized

Successful hard turning is dependent upon the entire machining system and not just certain discrete elements. As a way of summary the following items all relate to successful hard turning applications.

- A machine with a high dynamic stiffness.
- Efficient workholding devices.
- A correctly chosen CBN grade or other tooling material type.
- High quality cutting edges.
- Rigid tool mounts.
- Appropriate machining parameters.
- Part piece rigidity.
- Chip management and cooling systems.

HARD TURNING AND THE FUTURE

There is currently a great deal of research that is being undertaken in the area of hard turning with involvement from both universities and private companies. The primary driver behind these research and development activities is a reduction in manufactured part cost and improvements in operating efficiency and part quality.

Machine Technology

In the area of machine technology there are opportunities to develop and further enhance hard turning. The hydrostatic spindle is one such example. In machining operations the so-called "force loop" is formed in the path from the cutting tool to the spindle and it includes all of the elements that the cutting force passes through. Since the characteristics of the elements in the force loop are critical to performance, the hydrostatic spindle will complete the performance enhancement in this area. With the hydrostatic ways on one side, a hydrostatic spindle on the other and the correct combination of cast iron and polymer concrete in the middle, the machine performance will rise to much higher levels. The result will be lower consumable costs, improved part accuracy, roundness and finish, better equipment utilization and generally a more robust process. A machine with these capabilities will further expand the range of possible applications for hard turning.

One of the process areas, which have not received as much attention, has been hard milling. Some manufacturers have been quietly using this process, very effectively for several years on materials in the Rc 42-50 range. As we look at the evolution of machine tools we see a definite trend toward systems that can support multiple processes such as turning and milling. However, the requirements for the machine design can be somewhat different when optimizing for either turning or milling applications. This particularly true with the spindle design that uses conventional bearings. With a large range of spindle loads and duty cycle types for turning and milling it has been difficult to properly design for both applications with conventional ball bearings [7]. This is another distinct advantage of the hydrostatic spindle which does not have the life limitations based upon the type, direction and severity of the applied loads as found with the ball or roller bearing designs.

In the area of workholding the expectations are that more systems will be available for holding delicate parts and those parts which have low natural frequencies. New workholding systems will also employ techniques to actively introduce additional damping, minimize part distortion and safely accommodate higher spindle speeds.

The development areas of process technology and materials metallurgy are two disciplines that seem to progress together and where continual changes are and will be observed. In the process area, tooling and cutting techniques are needed to address the applications of hard drilling, tapping and cut-off. These operations are attempted but do not generally perform well in hard applications. Similarly, critical enhancements are needed in the area of high quality thread cutting. Until hard turning has been mastered and implemented and is considered a robust process, the inability to produce a high quality thread will clearly reduce the overall cost effectiveness of the technology. Development in hard threading is clearly an area that should be given a priority by both the tooling companies and the metallurgical organizations. In the area of material metallurgy it is fully expected that new alloys will continue to be introduced which may create dramatic effects on the process technology. Tooling materials and techniques will need to remain current to take advantage of the new materials technology as it evolves.

Research is underway at several institutions to understand and attempt to eliminate white layer from hard turning. White layer is in fact a layer at the material surface, which is observed to be nominally 1 mm thick or less. This layer cannot be seen by a visual examination and it normally requires a destructive sectioning, polishing and a metallographic examination to determine its presence. The layer appears white because it is a fine grain structure caused by a phase transformation due to the heat of the process followed by some quenching mechanism or high strain levels associated with the process [4]. Note that white layer occurs in both dry and wet applications and will also be seen in grinding as well as turning processes. In the current technology white layer can be removed by processes such as superfinishing.

The large majority of the parts, which are hard turned, are done so without a concern for white layer. The down side to white layer is specifically those parts where high contact stresses are present, such as bearing races. In this case the fatigue life of the surface is reduced because of the applied high stresses and a fully developed white layer. White layer is not fully understood but one thing that has emerged from current research is that white layer which is not present with a sharp tool may begin to form as the tool grows dull. A dull tool having higher temperatures or higher pressures can trigger either of the mechanisms described by Griffiths [4]. Interestingly, white layer is not limited to turning operations and does and can occur in grinding processes as well.

Since white layer formation has been observed to occur with dull tools, an automated tool condition monitoring system is being researched. Vision systems and other non-contact techniques will certainly play a role here as researchers find increasingly more effective ways to examine the tool for optimized tool life or to determine the set point, where beyond white layer formation becomes certain.

An area of current development that shows great promise for planning hard turning applications is software modeling of the cutting process. The program is based upon FEA (Finite Element Analysis) techniques, empirically developed mechanical properties and an extensive mathematical knowledge of the cutting process [3]. Animations of the tool tip under cut can demonstrate chip formations and can identify cutting forces, temperatures in the workpiece and the tool, heat production and flow and stresses in the tool. The process model is a three-dimensional representation of the nose-turning process using *AdvantEdge* [3] machining modeling software. The cutting tool geometry is fully described with a relief angle, nose and edge radii. The cutting tool is then oriented relative to the workpiece and given back, lead and side angles as shown in Fig. #9. This software is being developed to forecast the performance of cutting geometries and to predict optimized-machining parameters. In the simulation mode the program will advance the tool into the workpiece and graphically show the chip formation and its associated properties.

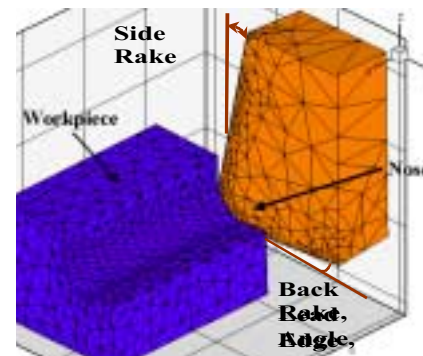


Figure # 9, AdvantEdge modeling software.

SUMMARY AND CONCLUSION

Hard turning is a viable process that has real and measurable economic and quality benefits. This is particularly true with a machine tool that has a high level of dynamic stiffness and the necessary accuracy performance. The more demanding the application in terms of finish, roundness and size control, the more emphasis must be placed upon the characteristics of the machine tool.

The hard turning process is similar enough to conventional “soft” turning that the introduction of this process into the normal factory environment can happen with relatively small operational changes. Even though many users choose to maintain the confidentiality of their hard turning operations, the general knowledge of the implementation strategies is becoming more widespread and readily available.

Extensive, ongoing research has been targeted in the hard turning area, with the likely expectation that additional benefits are soon to come in both the process and machine tool areas. Successful research programs will further enhance the desirability of this already effective process.

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