Systems Approach to Off-Round Grinding

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ABSTRACT: *Off-round grinding performed on CNC cylindrical grinding is a relatively new process. This paper takes a systems approach and discusses the various inputs and outputs and highlights the potential problems that production engineers face in implementing this new process. The effect of the inputs to the off-round grinding process such as the grinding machine, wheel, grinding fluid and the workpiece on the output parameters such as the component quality, the grinding power, surface finish, grinding wheel wear etc are discussed.*

Keywords: Systems thinking, manufacturing, grinding, off-round grinding.

INTRODUCTION

In the last 100 years the demand for increased accuracy and tolerance has led to increasingly sophisticated machines being developed. This has also led to increased productivity in the machining Industry. Figure 1 shows the improvements in the accuracy achieved over the last century (Komanduri et al. 1997). It shows that the development of precision grinding machines has contributed significantly to the lowering of the tolerances that can be achieved in grinding. The productivity in the machining off-round parts did not benefit from these developments, which continued to be produced on surface grinding machines. This paper documents the development of a new process for grinding off-round parts as a result of a development of a new CNC grinding machine at one of Australia's world class manufacturing company. This development has led to a quantum jump in the productivity and flexibility in the production of off-round parts.

Off-round parts such as square and rectangular ended punches have been traditionally produced using surface grinding machines, which involves mounting the punch on a table and grinding each side individually. This type of production results in lower production rates and low repeatability. Other off-round parts, such as cams, have been traditionally ground on special purpose machines which combine the movements of the rotational axis of the job and the infeed of the grinding wheel. The infeed motion of the grinding wheel is controlled by the use of templates, which in the case of cams are called master cams. This type of manufacturing process results in long lead times and high costs due to the need to produce the master cam template. A change over from one type of cam to another also involves large set up times. The development of sophisticated CNC cylindrical grinding machines with AC servo drives has enabled production of off-round parts by grinding directly from fully hardened round bar stock, and with no set up change. This welcome development in increased flexibility and productivity has been accompanied by certain pitfalls which production Engineers need to be aware of. This paper documents for the benefits of Production Engineers the findings of a study by Baliga (1999) on the use of cylindrical grinding machines in the production of off-round components. It also includes a discussion of parameters that affect the off-round grinding system and are sourced from literature on surface and cylindrical grinding.

THE OFF-ROUND GRINDING SYSTEM

The inputs to the off-round grinding system can be summarised as:

1. Grinding machine
2. Grinding wheel
3. Grinding fluid

4. Workpiece

Each of the inputs to the off-round grinding system will be discussed briefly along with the affect of each of these on the outputs of the off-round grinding system, namely the workpiece quality the grinding power and the wheel consumption. Figure 2 shows the off-round grinding system along with the inputs and outputs to the system.

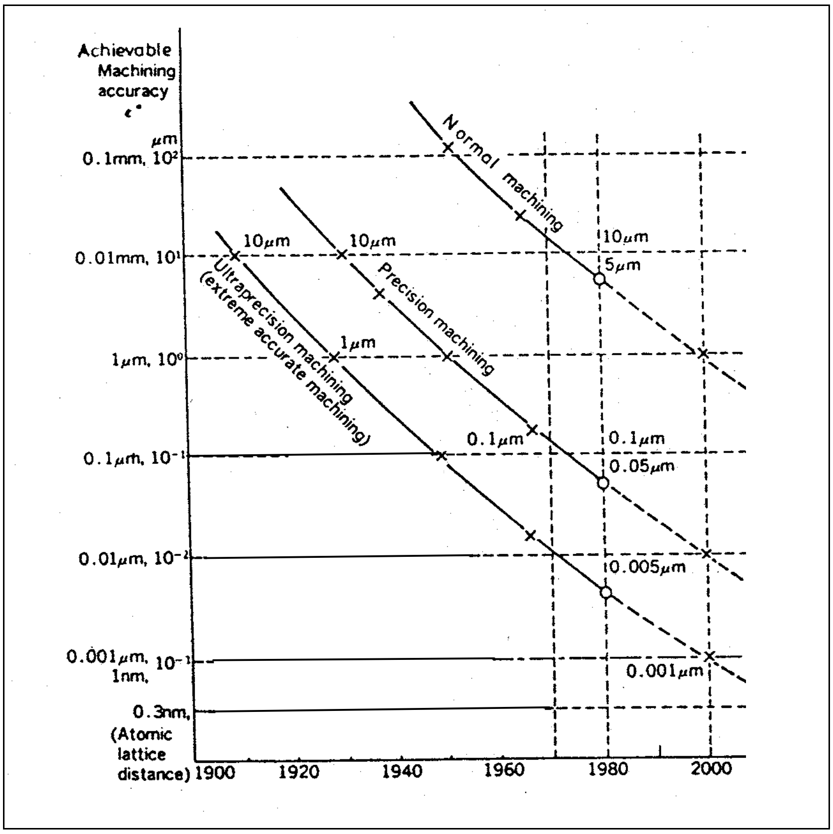

Figure 1: Improvement in the machining accuracy

Grinding Machine:

The development of CNC machines has enabled production engineers to grind a wide range of off-round cross-sectioned components with no set up change. Even though a cylindrical grinding machine may be able to generate the profile of the off-round component, force modelling by Baliga et al. (1998 b) indicates that the specifications required for the grinding machine drive system are appreciably higher than that required for round cross-sectioned components. In particular it was found that:

1. the peak grinding torque in punch grinding is over 15 times that of an equivalent sized round component.
2. in punch grinding the torque reverses direction. *When contact takes place above the line joining the wheel and punch centre, it was found that the grinding torque was positive and "pushed" the job.* At contact points below the centre line joining the wheel and punch centres the grinding torque was negative and "prevented" the rotation of the punch. This is in contrast to cylindrical grinding of round components where the torque is constant and always opposes the component rotation. The contact at a point below the line joining the grinding wheel and punch centres is shown in Figure 3.

The implications of these findings for the production engineer is to:

1. Ensure that the drives system on the CNC grinding machine is able to withstand the higher grinding torque generated during grinding off-round components. In the absence of the drive system being unable to withstand the increased torque of 15 times the normal torque, it is very likely to result in a "wheel grab" resulting in an accident and possible wheel breakage.
2. Ensure that the machine does not have backlash in the component drive system. A positive direct drive system without backlash will overcome the effects of the sudden reversal of torque direction.

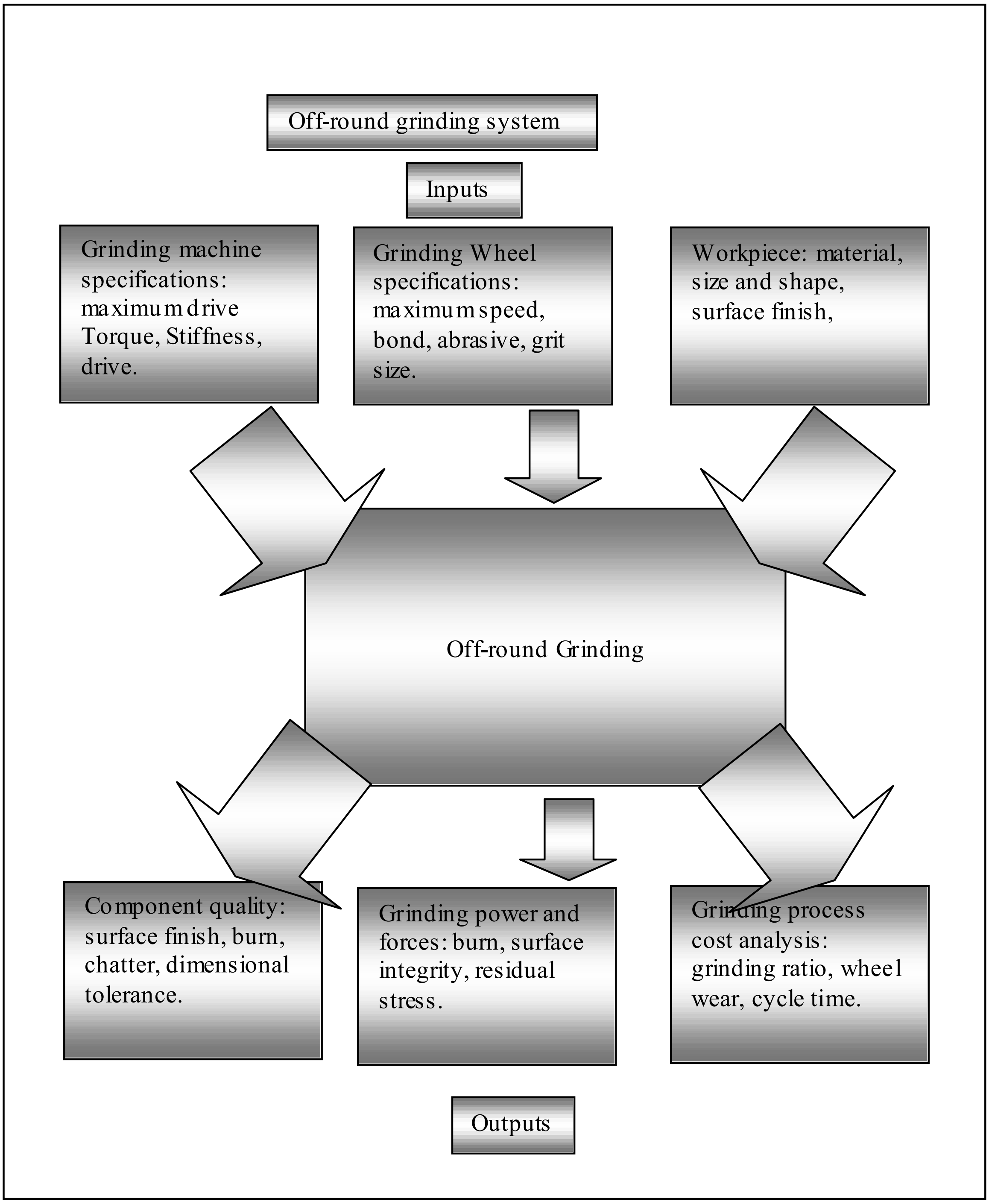

Figure 2: The off-round grinding system.

Studies by Snoeys et al. (1969) and Colding (1970) have reported on the importance of stiffness of the machine on the output parameters such as surface finish and wheel wear. The static deflection gives a measure of the stiffness of the machine and occurs as a result of the constant grinding load. A low stiffness results in lowering of the material removal rates. It has been shown by Baliga et al. (1998b) that in off-round grinding, the grinding load varies continuously and the load itself is much higher. It is thus especially important that a machine used for off-round grinding meets the stiffness requirements. One of the common problems that can be attributed to low stiffness is the chatter on the finished component.

Cylindrical grinding of round components is normally performed at constant rotational speed of the component drive in order to obtain constant peripheral velocity. A simulation of the punch grinding process by Baliga et al. (1998a) indicated that a constant rotational speed does not lead to constant peripheral velocity, and hence a constant material removal rate. It was found that the punch grinding process can be optimised by having a variable component drive system. Thus, it is important that a CNC grinding machine used to grinding off-round components be capable of providing a variable drive speed.

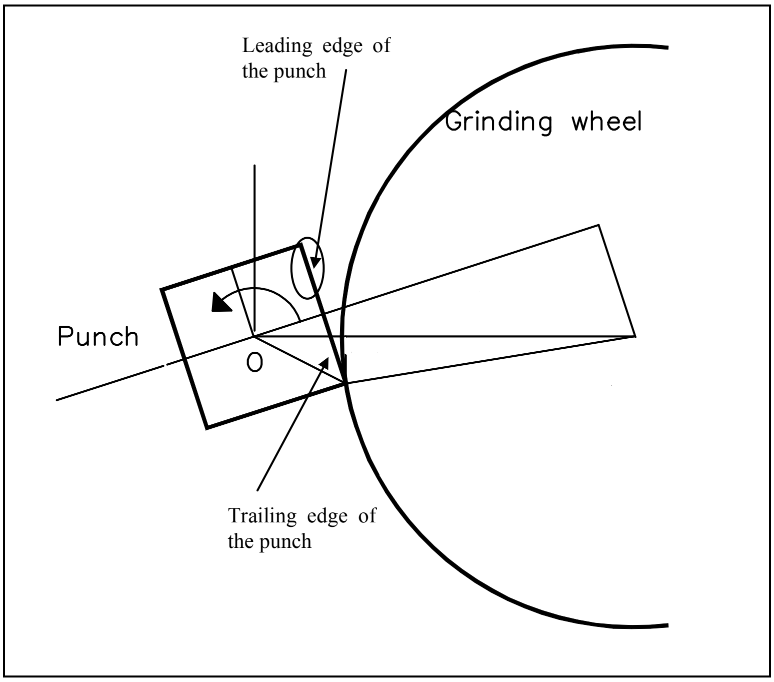

Figure 3: Off-round grinding with contact at a point below the line joining the wheel and punch centres.

Grinding Wheel:

Grinding wheel consumption cost is a large component of the total grinding cost. Grinding wheel wear increases with increase in material removal rate. Optimising the process for maximising the material removal and minimising the wheel wear is a crucial element in keeping the grinding cost under control. Thermal modelling of the off-round grinding process by Baliga et al. (1998c) indicated that:

1. An increase in material removal rate lowers the threshold for the onset of thermal damage.
2. An increase in material removal rate is best achieved by an increase in the rotational speed of the workpiece drive axis rather than by an increase in the depth of cut.
3. Use of a Cubic boron Nitride (CBN) grinding wheel leads to an increased threshold for the onset of thermal damage compared with an aluminium oxide grinding wheel.

The practical implication of this means that a CBN grinding wheel will allow a higher material removal rate as compared with the aluminium oxide wheel before the onset of workpiece burn.

Thus a grinding wheel as an input parameter, directly effects the outputs of the off-round grinding system, namely, the surface finish, the cost and the component quality as well. Proper selection of grinding wheel and use of appropriate grinding parameters are essential to optimising the grinding process.

Workpiece:

A particular feature of off-round grinding is that unlike cylindrical grinding of round components, the contact point between the wheel and component continuously changes along with the contact length. This change in the contact point causes a variation in the grinding torque acting on the grinding machine drive system. It was mentioned earlier that the peak negative grinding torque in punch grinding which resists the component drive system, is around 15 times that for an equivalent sized round component. Further, an 100% increase in the punch size leads to a 135% increase in the peak grinding torque. The implication of this finding is that the size of an off-round component is of particular importance in defining the specification/capacity of a grinding machine.

Grinding Fluid:

Grinding fluids play a critical role in maintaining the surface integrity of ground components. Within the published literature it is well accepted that grinding fluids help to reduce the bulk workpiece temperature and maintain close grinding tolerances. What is less evident, however, is the influence of the grinding fluid within the grinding zone. Again, this is particularly important in off-round grinding because the contacting length is much greater than in conventional grinding. The approach taken in this work was that the grinding fluid will cease to act as a heat sink at the boiling point of the grinding fluid due to the phenomenon of fluid film formation. This approach was used in the thermal model by Baliga et al. (1998c) and shown to accurately predict the threshold conditions leading to grinding burn. This was taken as confirmation that the grinding fluid is ineffective in removing heat from the grinding zone under conditions when grinding burn is taking place.

The results showed that the punch grinding heat energy input increases while grinding the trailing edge of the punch face (and repeated on each face). A doubling in the friction coefficient from 0.2 to 0.4 leads to a doubling in the peak specific heat energy input (226 W/mm to 452 W/mm) at the trailing edge of the punch. Thus a change in grinding fluid from neat cutting oil (friction coefficient 0.32) to soluble cutting oil (friction coefficient 0.48) will lead to an increased heat input to the grinding process.

A further consideration of the influence of the grinding fluid on friction in off-round grinding is the effect the change in friction has on the tangential grinding force and the peak negative grinding torque. The force model by Baliga et al. (1998b) showed that an increase in the friction coefficient leads to an increase in the peak negative torque. This is particularly critical for punch grinding since it can lead to the onset of instability in the form of wheel grab. This peak grinding torque has been shown to be proportional to the punch size.

Most studies (Des et al. 1970a, Des et al. 1970b, Yamamoto 1977) have shown that significant convective cooling does not occur in the grinding zone. However, grinding fluids do provide bulk cooling of the workpiece and, thereby, help the dimensional control. However, under workpiece burn conditions, the effectiveness of the grinding fluid to remove heat from the grinding zone rapidly falls. Hence, while grinding fluids play a diminished role in heat removal from the grinding zone under workpiee burn conditions, they do play an important role in reducing the overall heat input to the workpiece. This is primarily attributed to their influence on the friction coefficient. Thus, grinding fluids with lower friction coefficients are better suited when thermal damage is a problem.

Another aspect of grinding fluids that is distinct in the off-round grinding operations is that unlike cylindrical grinding of round components, the wheel workpiece contact point changes continuously. Thus delivery of sufficient grinding fluid to the grinding zone becomes critical and production engineers need to pay particular attention to this aspect. It is well recognised that the grinding wheel rotating at a high speed creates an artificial "wall" around itself, and grinding fluid at a sufficiently high pressure is required to penetrate this "wall". Use of air deflectors can minimise this effect and allow grinding fluid to enter the grinding zone.

CONCLUSION

Past improvements in the last 100 years have been mostly in surface grinding and cylindrical grinding of round components. A new development has been the use of CNC grinding machines for off-round grinding. This is a relatively new process which is quite distinct from cylindrical grinding of round components. This development has enabled a large variety of off-round shapes to be ground on these machines. This welcome development in flexibility and productivity also requires the production engineer to pay particular attention to several aspects. This paper looked at off-round grinding from a systems approach and highlighted the issues that need the attention of the Production Engineer prior to grinding off-round shapes on CNC cylindrical grinding machines.

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