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ANALYSIS OF FACTORS EFFECTING THE WORKPIECE TOPOGRAPHY OF THE CYLINDRICAL GRINDING SYSTEM

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Abstract

This paper overview the factors analysis in the cylindrical grinding system which effects the quality of the workpiece. The workpiece quality is effected by the vibration of the grinding system, grits on the grinding wheel, thermal damage, shadow phenomena, uneven protrusion height of grits, design of nozzle and hydrodynamic pressure at contact zone. In order to overcome these factors, overview of the solutions has been done, that focus on the dressing and the coolant of the grinding system in order to achieve the smooth finishing of the workpiece.

Key words: *Cylindrical Grinding Machine, Stability Analysis, Grits, Multiple Edges, Dressing Effect*

1. INTRODUCTION

The cylindrical grinding is a material removal process where a grinding wheel is rotating against the surface of the workpiece to do the machining and finishing process. The history of the grinding in manufacturing industry is almost 100 years old, although some sign of grinding was even found from neolithic times [Woodbury 1959]. In the early 20th century the foundation of modern grinding had been laid. Alden and Guest was the first one who brought grinding process into research and scientific studies [Alden 1914, Guest 1915]. Although, at that time much focus was at the macro level analysis.

The main goal with the grinding process is not only to remove the material but also to get the smooth shape of the workpiece. In the grinding phenomena, there are many factors that make the process complex and difficult to achieve the desired standard of the quality workpiece. Due to the complexity of the grinding process, work has been done on the modeling of the grinding system, topography generation and dynamics analysis which includes the time delay phenomena causing regenerative chatter in the system. Many micro level factors came into consideration after 1960 including study of single girt force and cutting effect on the grinding quality. Baul, worked on the grit factor distribution and grit height on the surface of the grinding wheel [Baul 1967]. Yoshikawa did modeling of grits coordinates spacing on the grinding wheel [Yoshikawa 1968]. The dynamic behavior of the grinding system has been studied by scientist in early days. Hahn was the first one who did study on the regenerative chatter issue in the grinding system [Hahn 1970]. Regenerative work has been followed by Thomson and Stepan, whose focus was on the time delay phenomena [Thomson 1986, Stepan 1989]. Though, grinding is a costly machining process as compared to turning, milling and drilling but still it is been used by 20-25% of all machining done annually in the United States [Malkin 1989]. Reasons, that make grinding preferable to other machining process despite of high cost is high accuracy and smooth finishing of the workpiece. In order to achieve high quality machining with grinding, high production rate and to low down the cost factor, research work is been carried out from vibration problem to all minute problems.

In this paper, factors effecting the cylindrical grinding system have been analyzed. The cylindrical grinding system does the cutting process and it undergoes through different stages during the grinding. The cylindrical grinding system depends upon macro as well as micro factors in order to get the smooth finishing of the workpiece. These factors are the grinding force, grit force, protrusion height factor, multiple edges of the grits, uneven distribution of the grits and hydrodynamic effect. Solution has been analyzed in order to avoid these factors by balancing the cylindrical grinding system, contact dynamics analysis study at micro-level, dressing of grinding wheel on appropriate time to remove unwanted grits and sharpens the grit edges, coolant position and hydrodynamics study of contact area in cylindrical grinding system.

2. CYLINDRICAL GRINDING SYSTEM

In the cylindrical grinding system, both the grinding wheel and the workpiece are rotating against each other. Figure 1 shows model of the cylindrical grinding system. The grits on the grinding wheel are the one responsible

for the abrasive cutting. The grinding wheel is rotating much faster than the workpiece, on contact the grinding wheel exerts a force in normal as well as tangential direction and removes the material from the surface of workpiece.

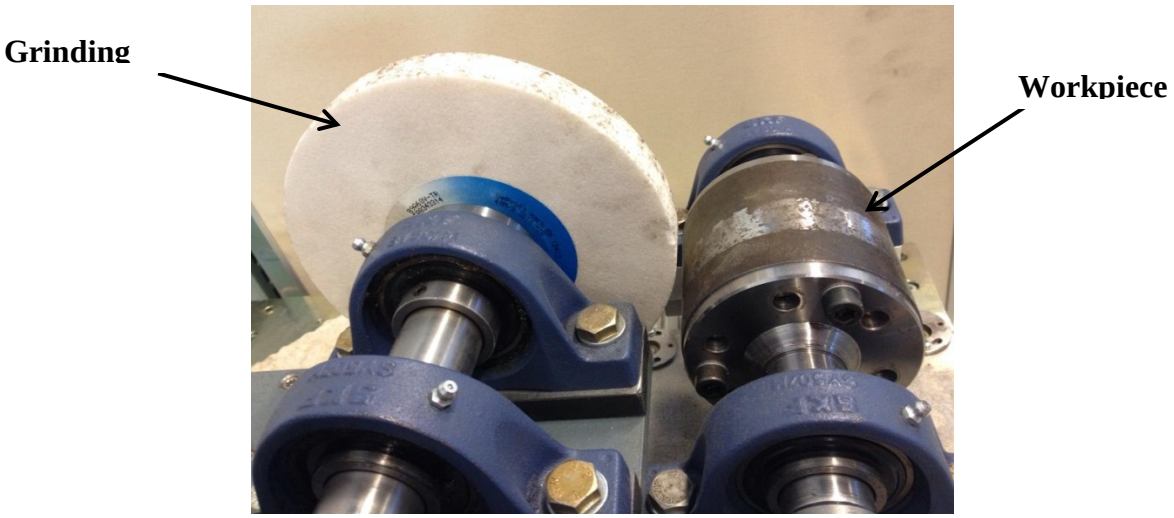


Figure 1. Cylindrical grinding machine model

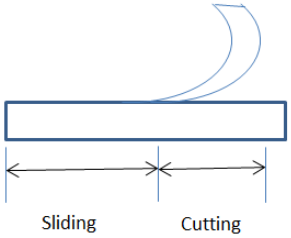


Figure 2. Stages of cutting mechanism

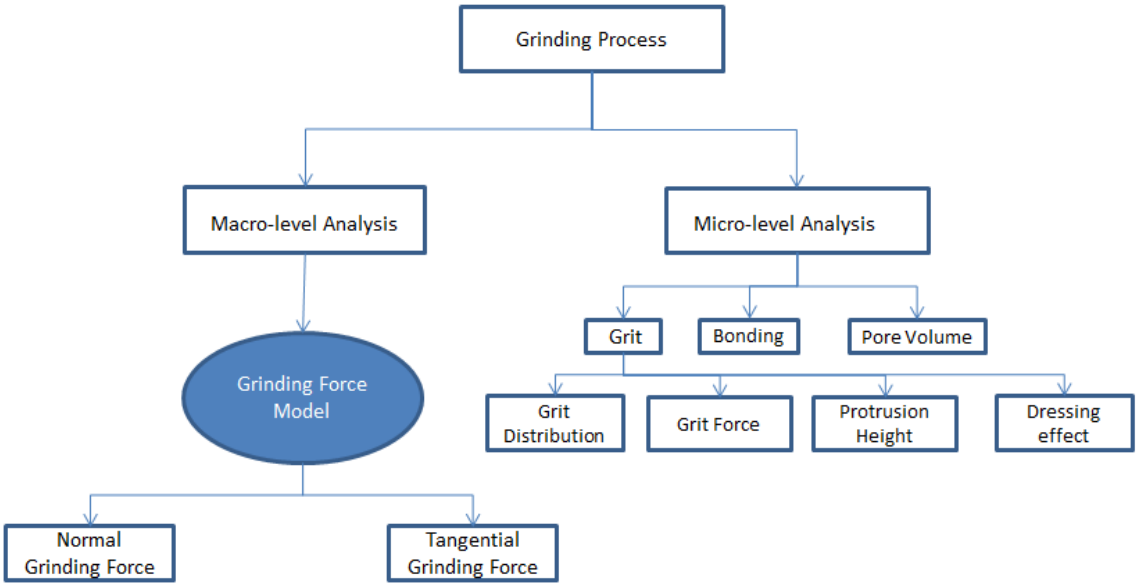


Figure 3. Analysis of the grinding process

When the grinding wheel and workpiece makes contact, the actual cutting process in contact zone at micro-level goes through different stages i.e. sliding and cutting as shown in Figure 2. Sliding stage is from the point grit starts to engage with the workpiece, while cutting stage responsible for the chip formation. [Malkin 1971, 2002]

3. ANALYSIS OF FACTORS EFFECTING THE WORKPIECE TOPOGRAPHY

The factors effecting the topography of the cylindrical grinding system are analyzed into two types, i.e. macro-level and micro-level analysis.

The grinding process analysis is shown in schematic diagram in Figure 3.

The macro-level analysis involves the contact grinding force phenomena. On contact between the grinding wheel and workpiece, system experience grinding force phenomena that depend upon the factors like rotational speed of the grinding wheel and the workpiece, depth of cut and the specific grinding energy. Macro-scopic level grinding system experience normal force phenomena and tangential force phenomena. Normal force is in the direction of where contact is been made while tangential force is perpendicular to the normal force.

The micro-level study involves many other factors though their effect seems minimal but their importance cannot be denied. These factors are mentioned in Figure 3, when the grinding wheel is rotating against the workpiece, the grits on the grinding wheel do the actual cutting process. Grits carries the importance at microscopic level for the fine smooth finishing of the workpiece. Factors effecting on these grits are bonding to grinding wheel, pore volume, height from the surface of grinding wheel and dressing effect.

Both micro and macro level factors effect the finishing of the workpiece, by working out on these factors can have effect on the cost saving. In order to get the smooth surface quality, flow chart in Figure 4 shows the factors analysis.

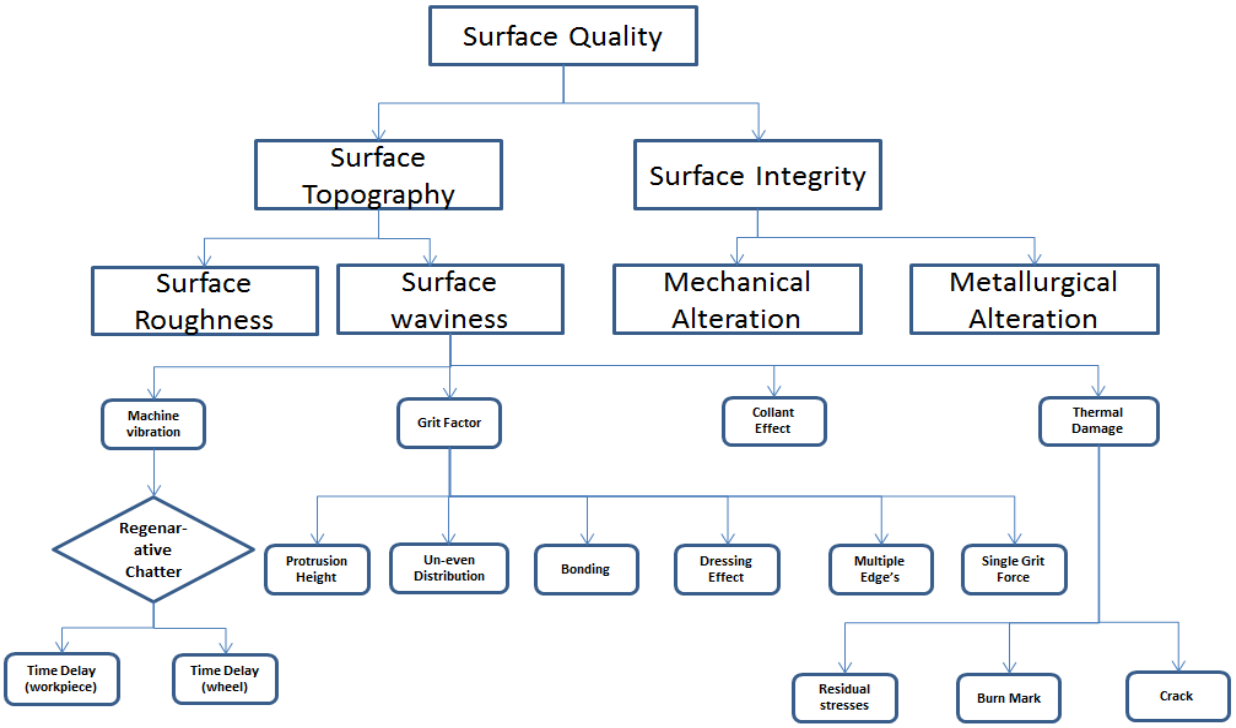


Figure 4. Factor effecting the surface topography

The quality of the workpiece depends upon the surface topography and surface integrity. Surface integrity is sub-divided into mechanical and metallurgical alteration while surface topography of the workpiece is effected by the roughness as well as waviness phenomena [Xuekun 2011]. Roughness is associated with the grinding cutting

process while waviness has been observed in the final shape of the workpiece. The waviness factor is because of machine vibration, grit factor, coolant effect and thermal damage. Vibration can be because of misalignment of the machine but at micro level factor of time delay has been considered due to rotational speed of workpiece and grinding wheel. In cylindrical grinding system, both the workpiece and grinding wheel are rotating and overlapping with time. The regenerative chatter phenomena is because of double time delay. Another important factor in smooth output of the workpiece is the grit factor. Grits on the surface of the grinding wheel are the one responsible for cutting during the grinding. Grits are important in the study of the grinding wheel because multiple factors come into play with time in grits.

3.1 Protrusion height factor

Protrusion height is defined as the distance of the grit peak from the surface of the grinding wheel, denoted by P_h as shown in Figure 5 [Xuekun 2010]. This protrusion height can vary in the grinding wheel.

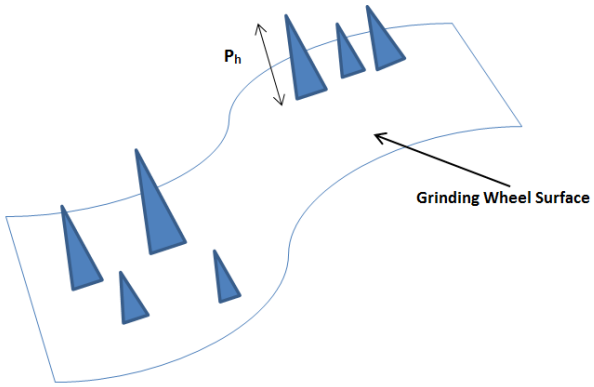


Figure 5. Protrusion height of the grits

When grinding wheel is rotating against the workpiece, smooth finishing cannot be achieved due to uneven protrusion height of the grits on the grinding wheel. Grit with long protrusion height cuts the part of workpiece more than the one with smaller height, leaving some residue on the workpiece surface. This phenomena plays a role at the micro level in the finishing of the workpiece. Recently much work has been done on different theories related to the topography of the grinding wheel in 1D, 2D and 3D topography models. Liao model [Liao 1995], Hou and Komanduri model [Hou and Komanduri 2003], Koshy et al. model [Koshy 1993] and Torrance and Badger [Torrance 2000] model are different topography models of the grinding wheel. All models proposed different distribution position of the grit and formularized grits position on the grinding wheel surface.

3.2 Shadow phenomena

In grit factors another important factor is the multiple edge of the grit. Figure 6(a) shows the ideal grit shape. It is assumed to be sharp single edge during grinding process but with time grits shapes adopt some changes. Usually grit will take the shape having multiple cutting edges as shown in Figure 6(b).

In multiple edge grit a phenomena occurred which is called a shadow phenomenon. In the shadow phenomena the multiple edges of single grit do cutting process according to own capacity leaving marks, wear and tear on the surface of the workpiece. As these edges makes cutting process inconsistent because of different length of cutting edges, which is assumed to be same sharp edge during the grinding process. This phenomena often goes unnoticed during the grinding process, but it carries an impact on the smooth finishing of the workpiece. Single grit force is another important factor that is been considered in recent times. Because it is the individual grit force that makes an impact on the force at the macro level in the contact dynamics.

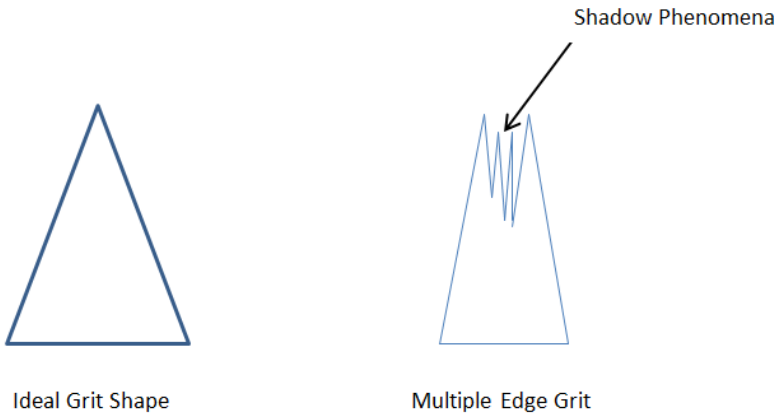


Figure 6. Shadow phenomena demonstration and comparison of ideal sharp and multiple edge grit

3.3 Thermal damage

Surface topography has been effected by the thermal damage. During the grinding process the grinding wheel and the workpiece are rotating at high speed because grinding process needs higher energy for material removal as compared to other cutting process. Energy is dissipated as heat due to which a high temperature has been observed at the grinding contact zone. This high temperature makes thermal damage in the contact zone which causes residual stress, fatigue, cracks and burns marks on the workpiece surface. Thermal damage effect can be avoided by lowering the material removal rate by reducing the grinding power but this effect to the overall cost of the product [Aaron Walsh 2004].

4. SOLUTIONS OVERVIEW TO OVERCOME THE FACTORS

These grinding micro level issues can be resolved if certain measures have been taken on time. Grit factor effect can be overcome if the dressing of the grinding wheel has been done timely and cooling of the grinding contact zone should have been done properly.

4.1 Dressing effect

Dressing phenomena is important in grinding process in order to obtain optimum results [Torrance 2000]. It is also considered to be as conditioning of the grinding wheel because it is used to sharpen the grits, remove the shadow phenomena and to make same protrusion heights of the grits in order to achieve the standard output in the form of smooth workpiece surface. When the grinding wheel is properly dressed, it will remove the unwanted grits from the surface of the grinding wheel. By determining the dressing depth of the grinding wheel protrusion height of all grits can be made same. The shadow phenomena is overcome by the dressing effect because it removes the multiple edges of the grits and makes them ready for the smooth cutting process. By removing all the unwanted layers and the residue of workpiece from the grinding wheel surface, dressing clear the path for the coolant among the grits. Clearance in cooling path will save the grinding process from thermal damage effects. Dressing of grinding wheel ensures the long life of grinding wheel as well as maintains the high grinding standards. Dressing phenomena schematic is shown in Figure 7.

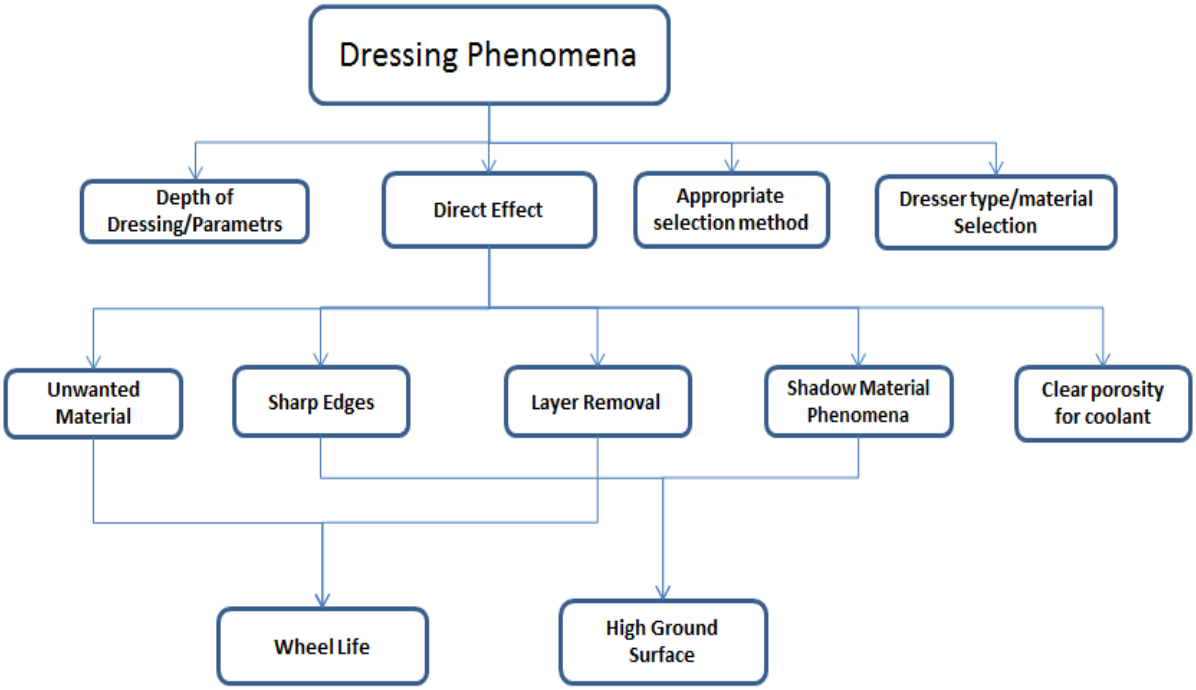


Figure 7. Schematic of dressing effect in the cylindrical grinding system

Important factors that is to be considered in dressing is its selection method, it can be done in two different ways, stationary dressing toll and the cylindrical dressing toll.

Both types of dressing are shown in Figure 8

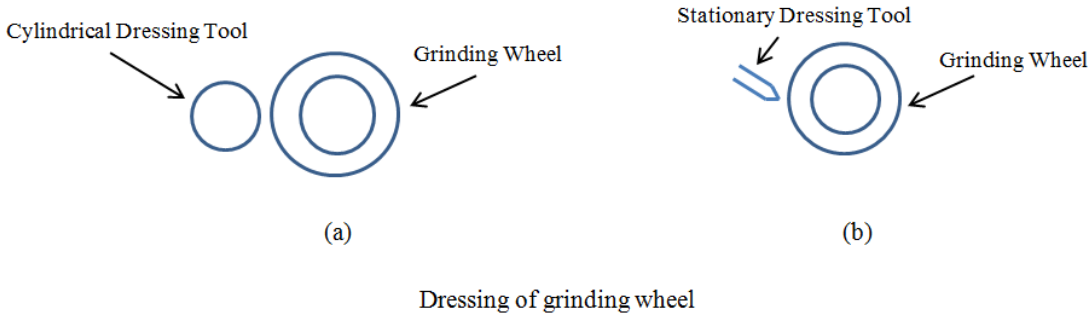


Figure 8. (a) Cylindrical dressing (b) Stationary dressing

The cylindrical dressing tool is shown in Figure 8(a). Dressing toll is rotating against the surface of the grinding wheel and removes all the extra materials and damaged grits from the grinding wheel. In contrast to cylindrical dressing tool, stationary dressing tool has a rotating grinding wheel parallel to stationary diamond dressing toll as shown in Figure 8b. Diamond dressing tool shapes can be of various types e.g. rough, pyramid, cone, flat and wedge. The use of any of these types depends upon the type of dressing needed for the grinding wheel. The diamond size on the other hand depends upon the diameter of the grinding wheel. Table 1 shows different size of the diamond tool according to the diameter of the grinding wheel.

Grinding Wheel Diameter (inch)	Single Point Diamond Size (carrot)
Up to 3	1/5
3 To 7	1/4
8 To 10	1/3
11 To 14	1/2
15 To 20	3/4
Over 20	1

Table 1. Dressing tool size according to grinding wheel diameter [Loan 2007]

4.2 Cooling effect

In order to avoid the effects of thermal damage, chip removal from contact zone and lubrication, coolant has been used during the grinding process. Grinding coolant effect on the whole grinding process is shown in schematic diagram in Figure 9. The advantages of the coolant usage during grinding are smooth workpiece quality, enhance longer grinding wheel life and high removal. There are certain factors that have to be considered during coolant in grinding process. The grits are bonded to grinding wheel in a way that they can sustain certain pressure and force during the grinding process. If the grinding fluid has not been provided with proper pressure, it can break the bonding of the grits from the surface of the grinding wheel. Another issue that needs to be focus during the grinding process is the mist problem. Mist erodes the surface of the grinding wheel, which later has an impact on life of the grinding wheel. The smooth and clear surface of the grinding wheel is necessary to achieve the desired results in term of smooth workpiece.

In the study of the grinding coolant effect, one factor that has to be considered is the hydrodynamic analysis. This factor has been studied from three different angles i.e. fluid pressure, flow rate in contact zone and method of nozzle application to the cylindrical grinding system. Typical method that has been followed in the grinding is to have maximum fluid pressure in order to obtain the maximum efficiency. The problem has been identified that hydrodynamic fluid pressure can be generated in this case before the contact zone, this will effect the depth of cut during grinding and overall machining accuracy. Li, modeled the hydrodynamic pressure for the high speed precision grinding based on Navier-Stokes equations and continuous equation [Li 2011]. Hydrodynamic pressure is directly proportional to the velocity of grinding wheel while pressure has inverse relation to gap between the wheel and the workpiece. The simulated results showed that highest pressure has been obtained when there is a minimum clearance between workpiece and the grinding wheel. The maximum pressure value has been obtained with the maximum surface velocity of the grinding wheel.

Nozzel for fluid delivery and its position in grinding system is as important as fluid pressure and flow rate. Sun-Kyu Lee proposed different positions of fluid delivery systems and their effects to the grinding system [Sun-Kyu Lee 2004]. Among different types of the nozzles, shoe nozzle is the one found suitable for the grinding wheel. Shoe nozzle is mounted just above the grinding wheel, which act as air scrapper that makes turbulent air away from the grinding wheel. Powell did the work on the designing of the nozzle and he analyzed that shoe nozzle should be as close to the grinding wheel and workpiece as possible [Powell 1979]. This will not only reduce the leakage but also minimize the grinding power by lowering the fluid flow rate.

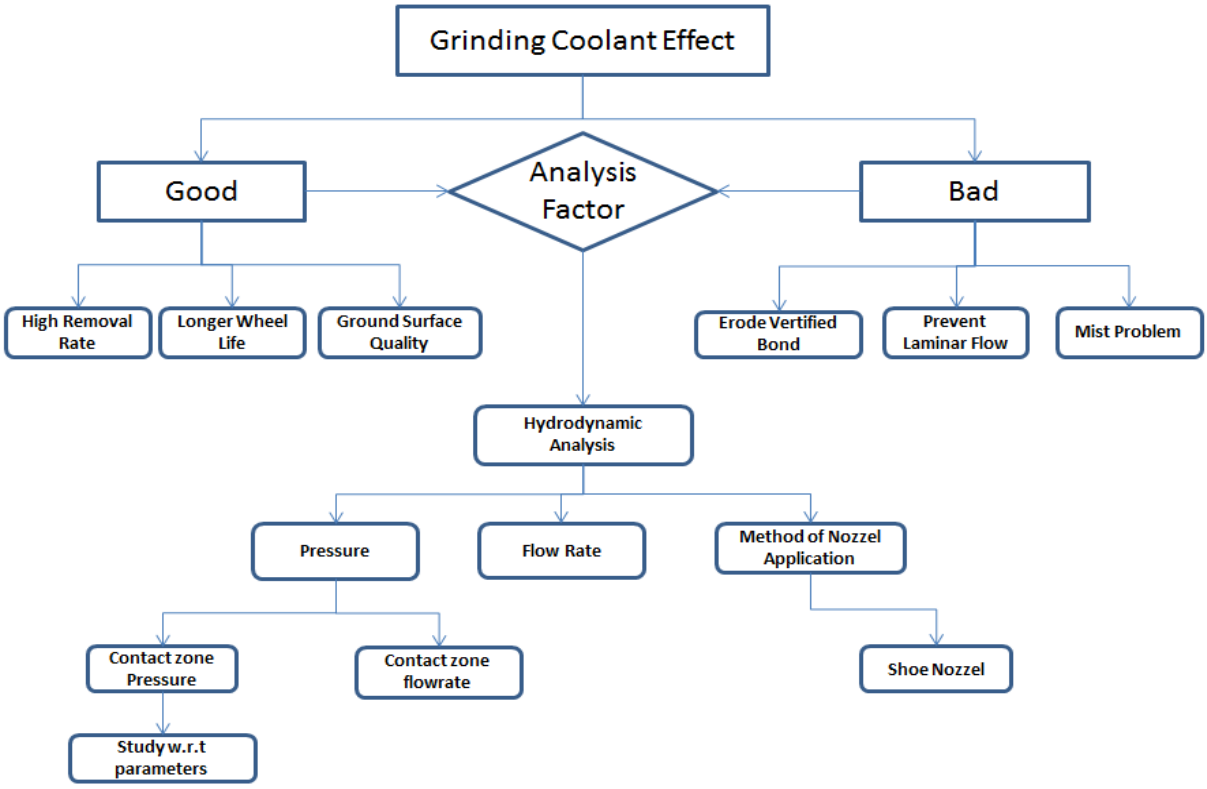


Figure 9. Schematic of grinding coolant effect

CONCLUSIONS

The cylindrical grinding system is a complex and precise machining process. There are many factors involve in this process at micro and macro level that effects the quality of ground workpiece. In this paper, the overview of these factors analysis has been done which effects the topography and the quality of the workpiece. Vibration is one of the factors effecting the workpiece, it is due to the misalignment and the time delay phenomena of the grinding wheel and the workpiece. Protrusion height of the grits is due to random distribution and the height of the grits, whose effect can be seen in the final shape of the workpiece. During the grinding, the edges of the grits do not remain in the ideal shape and single sharp grit converted into multiple edge grit. These multiple edges of the grits act as individual cutting grit and generate the shadow phenomena, which cause uneven cutting of the workpiece. Thermal damage factor is also considered important as grinding wheel and the workpiece are rotating with high speed against each other, and it can cause burn marks on the surface of the workpiece.

The overview of the solutions to overcome these factors is the dressing and the thermal cooling of the grinding system. Dressing of the grinding wheel will keep the same height grits and to remove multiple edges of the grits on the surface of the grinding wheel. This will help to overcome the shadow phenomena and protrusion height factors. Cooling of the grinding system is also important in term of the thermal damage. It will remove the grinding residue and clear path for the grits to penetrate into the workpiece surface. Solutions overview analysis shows that working out on these factors ensures the long life of the grinding wheel and smooth finishing of the workpiece.

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REFERENCES

Alden, G. I. 1914. “Operation of Grinding Wheels in Machine Grinding.” Trans. Am. Soc. Mech. Eng. 36, 451–460.

Aaron Walsh, 2004, “Mathematical Modelling of the Crankshaft Pin Grinding Process”. PhD Thesis, Deakin University, Australia.

Baul, R. M and Shilton R, “Mechanics of Metal Grinding with Particular Reference to Monte Carlo Simulation”, Proceedings of the Eight International Machine Tool Design and Research Conference, 1967, pp. 923.

Li. C.H. et. al., “Investigation of Hydrodynamics Pressure in High-speed Precision Grinding”. Advance in Control Engineering and Information Science, Procedia Engineering 15 (2011), pp. 2809-2813.

Hahn, R. S., Lindsay, R. P., “The Effect of Parameter Variation in Precision Grinding”. Paper No. 70-PROD-1, American Society of Mechanical Engineers (ASME), New York 1970.

Hou Z. B, R. Komanduri, On the mechanics of the grinding process-Part I. Stochastic nature of the grinding process, International Journal of Machine Tools and Manufacture 43 (15) (2003), pp. 1579–1593.

Koshy P, V.K. Jain, G.K. Lal, A model for the topography of diamond grinding wheels, Wear 169 (2) (1993) 237–242.

Koshy P, V.K. Jain, G.K. Lal, Stochastic simulation approach to modelling diamond wheel topography, International Journal of Machine Tools and Manufacture 37 (6) (1997), pp. 751–761.

Lindsay, R. P., “Dressing and its Effect on Grinding Performance, Society of Manufacturing Engineers”. Paper No. MR69-568, S.M.E., Dearborn, Michigan (1969).

Liao T.W., Fractal and DDS characterization of diamond wheel profiles, Journal of Materials Processing Technology 53 (3–4) (1995), pp. 567–581.

Loan D. Marinescu, Mike Hitchiner, Eckart Uhlmann, W. Brian Rowe, Ichiro Inasaki, 2007, ‘’Handbook of Machining With Grinding Wheel’’.

Malkin, S, 1989, Grinding Technology, John Wiley & Sons: New York.

Malkin, S, Cook, N.H., 1971. The wear of grinding wheels, part1, attritious Wear. Transactions of the ASME, Journal of Engineering for Industry. Series B 93, 1120–1133.

Malkin S, 2002. Grinding Technology Theory and Applications of Machining with Abrasives (Translated by Cai Guangqi, Gong Yadong, Song Guiliang). Northeastern University Press, Shenyang, pp. 76–88 (in Chinese).

Powell, J. W, C 1979, “Application of Grinding Fluid in Creep Feed Grinding”, PhD thesis, University of Bristol.

Stepan Gabor, 1989 ‘’Retarded Dynamical Systems: Stability and Characteristics Functions,’’ Longman Scientific and Technical, John willey and sons, Inc., New York.

Sun-Kyu Lee et. al., 2004, “Effects of Minimizing Hydrodynamics Pressure in Ultra-Precision Mirror Grinding”, International Journal of Machine Tools and Manufacturing 44. pp. 1031-1036

Thompson R. A, 1986 ‘’On Double Regenerative Stability of a Grinder: The Theory of Chatter Growth,’’ Journal of Engineering for Industry, Vol. 108.

Torrance, A and Badger, J. A., 2000. “The Relation between the Traverse Dressing of Vitrified Grinding Wheels and Their Performance.” Int. J. Machine Tools & Manuf. 40, 1787–1811.

Woodbury, R. S. 1959. History of the Grinding Machine. The Technology Press, MIT, Cambridge, MA.

Xuekun Li, Yiming Rong, “Framework of Grinding Process Modeling and Simulation based on microscopic interaction analysis” Robotics and Computer-Integrated Manufacturing 27 (Elsevier). pp. 471-478.

Xuekun Li, 2010, “Modeling and Simulation of Grinding Processes based on a virtual Wheel Model and Microscopic Interaction Analysis”. PhD thesis, Worcester Polytechnic Institute.

Yoshikawa, H. and Sata, T., 1968, “Simulated Grinding Process by Monte Carlo Method”, Annals of the CIRP, Vol. 16, pp. 297.