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Machining Bevel Gears on the Engine Lathe: A Feasibility Exploration

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Abstract. Bevel gears are among the most complex components in mechanical engineering. They are used in transmitting power and motion in specialized applications**.** Machining is reaffirmed as the most common and accurate method of producing gears. The study however shows that only special and costly facilities not commonly found in machine shops are used to execute bevel gear machining. The engine lathe as the usually available machine tool in machine shops was seen to be inadequate for producing these gears by the conventional machining operations on it. Feasibility for jobbing production of bevel gears to meet local purpose-built needs without use of extra bought costly machines was conducted. The study shows that straight external bevel gears can be produced on the lathe with suitably selected milling cutters using prepared bevel blanks and developed suitable attachment. Spiral external bevel gears can also be produced on the lathe by axial hobbing using; developed suitable attachment, selected hobbing cutter, and proper size of prepared cylindrical gear blanks. Accessories, structural rigidity, excess power, versatility, and on-performable motions of the lathe can be exploited to achieve the machining.

Key words: Bevel gear, purpose-built, machining, advantages, workshops, possibility

Introduction

Gear is a toothed wheel which meshes without slip with some other suitable toothed device to provide torque to transmit power where required in any moving device. Different types of gear include spur gears, rack and pinion, internal ring gear, helical gear, helical rack gear, double helical gear, face gear, worm gear, double enveloping worm gear, hypoid gear, straight bevel gear, spiral bevel gear, and screw gear or crossed helical gear (Jain & Chitale, 2014.; Pushpalatha *et al*, 2018).

Bevel gears are used to transmit motion between shafts that have intersecting center lines. The intersecting angle is normally 90 degrees but may be as high as 180 degrees. Straight bevel gears have tapered conical teeth which intersect the same tooth geometry. The teeth of bevel gears can also be shaped in a curved manner to produce spiral bevel gears, which are known to produce smoother and quieter operation than straight cut bevels. Bevel gear are used in diverse applications such as locomotives, differential drives which can transmit power to two axles spinning at different speeds such as those on cornering automobile, printing presses, cooling towers, power plants, steel plants, railway track inspection machines, helicopter power transmission, thermal power generation applications, ship propulsion units, wind turbines, etc (Hyatt & Piber, 2014; Jain & Chitale, 2014; Pushpalatha *et al*, 2018).

Although gears can be produced by different manufacturing processes, machining is the most common and accurate process of producing gears (Hyatt & Piber, 2014; Jain & Chitale, 2014; Pushpalatha *et al*, 2018). The traditional methods of producing gear by machining include gear forming by milling, gear hobbing, gear shaping and bevel gear cutting. Machining is also usually used to achieve the final dimensions, shape and surface finish of gears manufactured by other processes such as casting, forging, extrusion, powder metallurgy, rolling, and blanking. The choice of gear machining method depends on the type of gear to be machined, size of gear, quantity and type of gear required, desired accuracy of the gear, and cost and availability of the production equipment. The tooling required also tends to vary based on the type of gear (Hyatt & Piber, 2014; Jain & Chitale, 2014; Pushpalatha *et al*, 2018).

The Traditional Methods of Gear Machining

In gear cutting by forming, the shape of the cutting edge of the cutting tool is identical with the shape of the space between the gear teeth. Milling and broaching machining operations are usually employed to cut-form gear teeth. In form milling, the form cutter travels axially along the length of the gear tooth at the appropriate depth to produce the gear tooth. After cutting each tooth; the cutter is withdrawn, the gear blank is rotated, and the cutter proceeds to cut another tooth. The process continues until all the teeth are cut.

Broaching is another traditional method that is often used to produce gear teeth. Broaching is particularly applicable to internal gear teeth cutting. The broaching process is rapid, and produces gears with fine surface finish and high dimensional accuracy. Nevertheless the process is disadvantageous in that broaches are expensive and a separate broach is required for each size of gear. This makes the process suitable mainly for high-quantity production of gears (Boral *et al*, 2018).

In traditional gear generating, the cutter and gear bank behave as mating gears in working contact. In the process, involute curves are developed by straight cutting edges of the cutter and the tooth flanks are obtained as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair. Cutting of gear teeth by the generating method makes use of certain relative motion between the work gear and the cutter during machining. Gear generating methods produce with one cutter theoretically correct gear-teeth profiles regardless of the number of teeth desired on the gear. A cutter for a given pitch diameter may be used to cut gear with any number of teeth. All teeth cut by the cutter will have theoretically correct profiles, and all the cut gears will mesh interchangeably. The common processes used for generating gear teeth are, shaping and milling by rack planning (Bouzaki *et al*, 2008). The principal motions involved in rotary gear shaping are; cutting motion, return stroke, and indexing motion. The cutter and gear blank are connected by gears so that they do not roll together as the cutter reciprocates for cutting. First the cutter has to cut its way to the desired depth. The cutter and gear blank then rotate slowly together as the gear teeth are cut in the gear blanks as shown in Figure 1. Slightly more than one revolution of the work is required for the rotary cutting process (Bouzaki *et al*, 2008; Li *et al*, 2017).

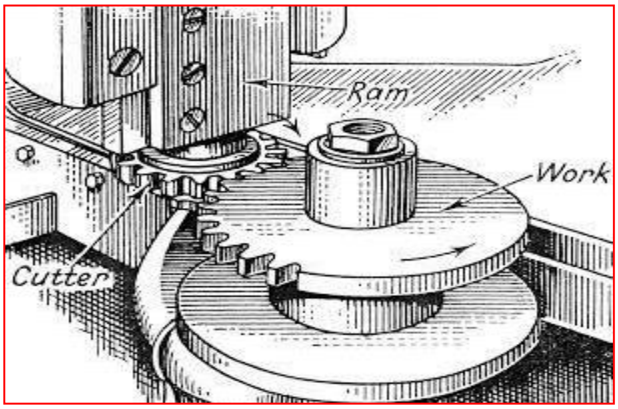


Figure 1. Principle of gear generation by rotary shaping (Boral *et al*, 2018)

The principle in the rack planing generation of gears is that a rack type HSS cutter that has rake and clearance angles reciprocates to accomplish the machining action while rolling type interaction with the gear blank like a pair of rack and pinion as shown in Figure 2 (Li *et al*, 2017). The favourable and essential applications of this method include (Li *et al*, 2017):

i. Macining of mderate size straight and helical toothed external spur gears with high accuracy and finish.
ii. Cutting the teeth of double helical or herringbone gears with a central recess (groove)
iii. Cutting teeth of straight or helical fluted cluster gears.

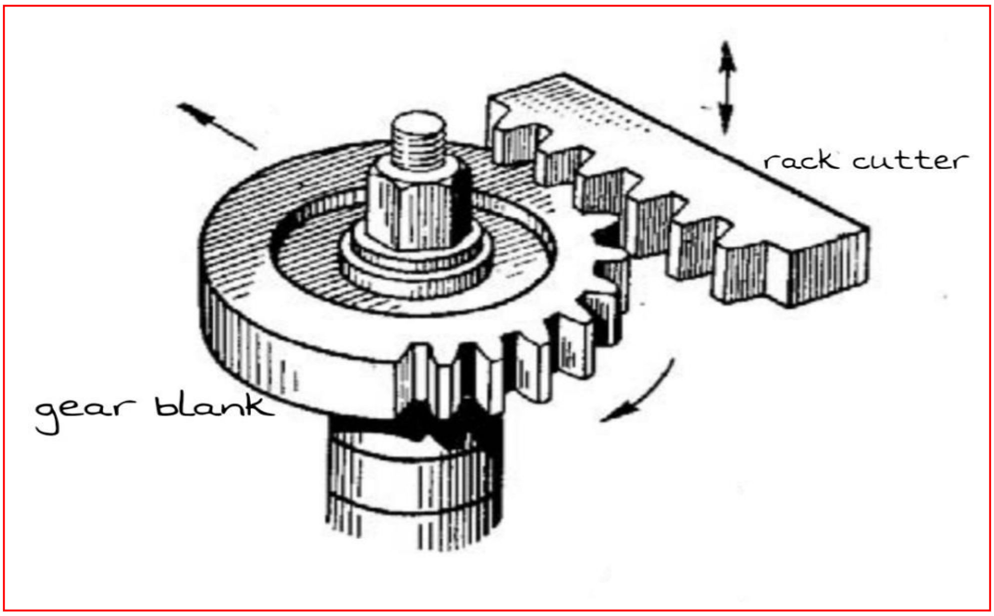


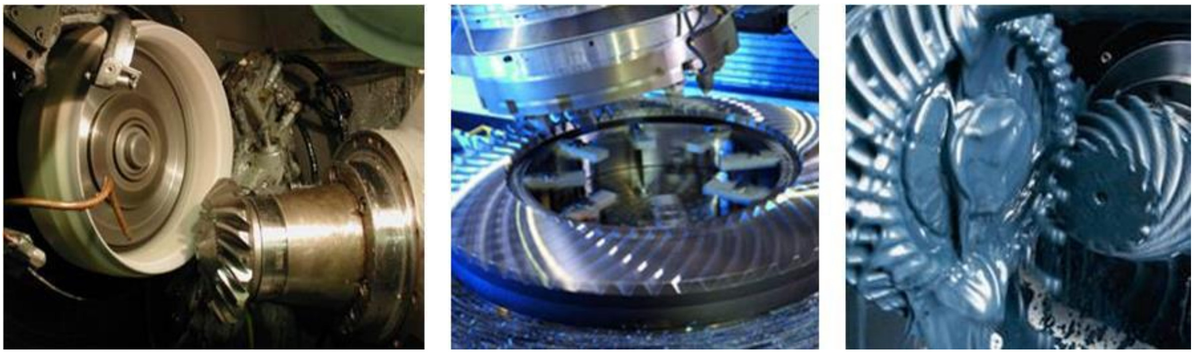
Figure 2. Principle of gear generation by rack planning (Li *et al*, 2017)

In the hobbing method of gear machining, gear teeth are progressively generated by a series of cuts with a helical cutting tool whose cutting teeth are replica of the gear teeth to be cut formed. In the hobbing process the cutter is rotated, moved radially and pressed against the blank which also rotates to form the teeth. All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut (Li *et al*, 2017; Shewale, & Suryawanshi, 2016).

Developments in Machining of Bevel Gears

Bevel gear cutting is a very specialized area of gear production. Bevel gear cutting involves use of special type of machine for each variety of bevel gears to be produced. Some of the bevel gear types along with the type of machines required are; Gleason, Oerlikon, Hypoid Zerol, etc (Chaphalkar, 2013). Bevel gears were first produced over 53 years ago. Although there have been several incremental improvements to the initial methods, the fundamental principles of machining these gears remain the same. Historically, there were two main ways to produce bevel gear. One method involved the use of specialized equipment and tooling. The other method used very simple tools (end mills) and required solid model of the gear. It was a compromise either way in using the methods. For the first method, customers had to have special skills to prepare or modify the tooling and or wait for the right tooling to arrive. For the second method, the productivity of the process was lower and the solid models were never right or complete enough to get good surfaces and contact patterns. In addition, the two methods required completely different operator skill sets, machines, and programming software (Gadakh*et al*, 2016; Chaphalkar, 2013).

Advances in multi-axis control systems, 5-axis milling/multi-tasking machines, and CAD/CAM systems provided more appropriate media to generate bevel gears in general purpose machines, even with standard milling tools. For example, spiral bevel gears are usually generated by a continuous-cutting procedure using special gear generating machines, categorized according to the method of manufacture. These different methods are: generation by hobbing in part with cutter head (Gleason´s gearing), generation by continuous spiral hobbing with cutter head (Cyclo-Palloid System of Klingelnberg and Oerlikon System) and generation by continuous spiral hobbing with conical or cylindrical hob (Palloid System of Klingelnberg) as shown in Figure 3 (Kawasaki, 2010; Chaphalkar, 2013).



A B C

Figure 3. (A) Gleason´s gearing; (B) Cyclo-Palloid System of Klingelnberg and Oerlikon; (C) Palloid System of Klingelnberg (Kawasaki, 2010)

Within the last 10 years, development of multi-tasking machines and new programming software combined with newly-developed machining processes created an opportunity to give a new glamour to bevel gear machining and usher in 21st century advances. Multi-tasking machines are machines with milling and turning capabilities. It is a sort of lathe and milling machine combined into one. Multi-tasking machines can be considered as two main types: Turn-Mill and Mill-Turn. Turn-Mill machines are typically suitable for producing pinions while Mill-Turn machines are suitable for gears. These are 5-axis machines that can perform many manufacturing processes. These machines can machine all sides of the parts, and, in many cases, machine a part to completion. These machines are used in many different industries including aerospace, medical, industrial, tooling, and now gear manufacturing. The tools for these new manufacturing processes are simple, (end mills or disc cutters) with no special geometry for any specific gear form or tooth. The machines do not require any special option to make them produce gears. The machines use programming software to effectively handle complexity of bevel gear geometries in production (Kawasaki, 2010; Chaphalkar, 2013).

Drawbacks in the Special Machines

The most significant disadvantages in the use of the special bevel gear cutting machines are:

i. Their high cost to manufacturers.
ii. Large complexity of control and amount of programming that the machines require.
iii. High knowledge of controlling and programming the machines required by personnel manning them.
iv. Maintainability and availability question of the machines.
v. Longer machining time involved.

In particular, the use of these machines can have big effects on the production of small and medium batch sizes because the investment cannot be paid off as quickly as it can with large batch production. There are also growing demands on producers of gears to ensure that their production processes are; cost-efficient, productive, and of the highest quality in order to fulfill the customer's demands for durability and price and remain competitive. The foregoing disadvantages can necessitate in-house arrangement for producing custom-built bevel gears to meet local needs (Dalvi *et al*, 2017; Kawasak, 2010).

The aim of this paper is to conduct a feasibility of machining external bevel gears on the engine lathe to meet local jobbing or purpose-built needs where special machines are not found such as in workshops and small scale industries, and for relevant research interests.

The Feasibility Exploration

A literature survey of machine tool types shows that the lathe is the oldest and most versatile type used in machine shops. There are various types of lathes with diverse uses. All lathes have similar principle of machining work pieces but differ in terms of strength, operational speeds, size and construction, degree of automation, processing capacity, control, rigidity, supports, accuracy and mechanism of tool control. Apart from its unique function as a turning machine for production of cylindrical and some other symmetrical components, the lathe can be used in limited ways to perform other machining operations such as drilling, boring, reaming, milling, threading, gear cutting, polishing, grinding, and even non-machining operations such as spinning that can be done on most of its sister machine tools. The probability of finding the engine lathe in any workshop is higher than that of any other machine tool (Álvarez *et al*, 2015; Amadi, 1996; Hyatt & Piber, 2014; Tuleun & Guma, 2006). The engine lathe is therefore the most suitable type of machine tool in machine shops that can be adapted to produce bevel gear. The challenges of producing bevel gears on the engine lathe are however feasibility, cost and productivity (Amadi, 1996).

Assessment of the Lathe Features for Gear Machining

The lathe is made and provided with many accessories such as: follower rest, steady rest, angle plates, face plates, catch plates, 3-jaw chuck, 4-jaw chuck, various types of centers, various mandrels, and attachments that can be exploited to perform different machining processes including gear cutting on it (Amadi, 1996; Gadakh *et al*, 2016). The lathe motor power capacity is also not fully utilized during normal machining operations on the lathe, so there is excess power from the lathe motor that can be tapped and used to drive an auxiliary cutter or machining device of an attachment to the lathe (Álvarez *et al*, 2015; Tuleun & Guma, 2006). The principal parts and movements that can be performed on the lathe and the level to which gear can be cut on the machine tool were surveyed. Figure 4 shows the principal parts of the engine lathe and movements that can be performed on the machine tool (Álvarez *et al*, 2015; Tuleun & Guma, 2006). The survey shows that spur gears can be machined on the engine lathe but bevel gears cannot be produced on the lathe. Spur gears are produced on the engine lathe in a number of ways. One common way of achieving the production is by holding a suitable milling cutter in a rotating arbor held between the lathe centers, while a suitably prepared blank with the overall desired size and profile of the desired gear to be cut is held on the cross slide of the lathe saddle longitudinally and integral with a spring loaded indexable master gear and cut by the cutter whilst crosswise in-feed movement of the blank to the cutter is provided manually through the cross slide as shown in Figures 5a & b (Amadi, 1996).

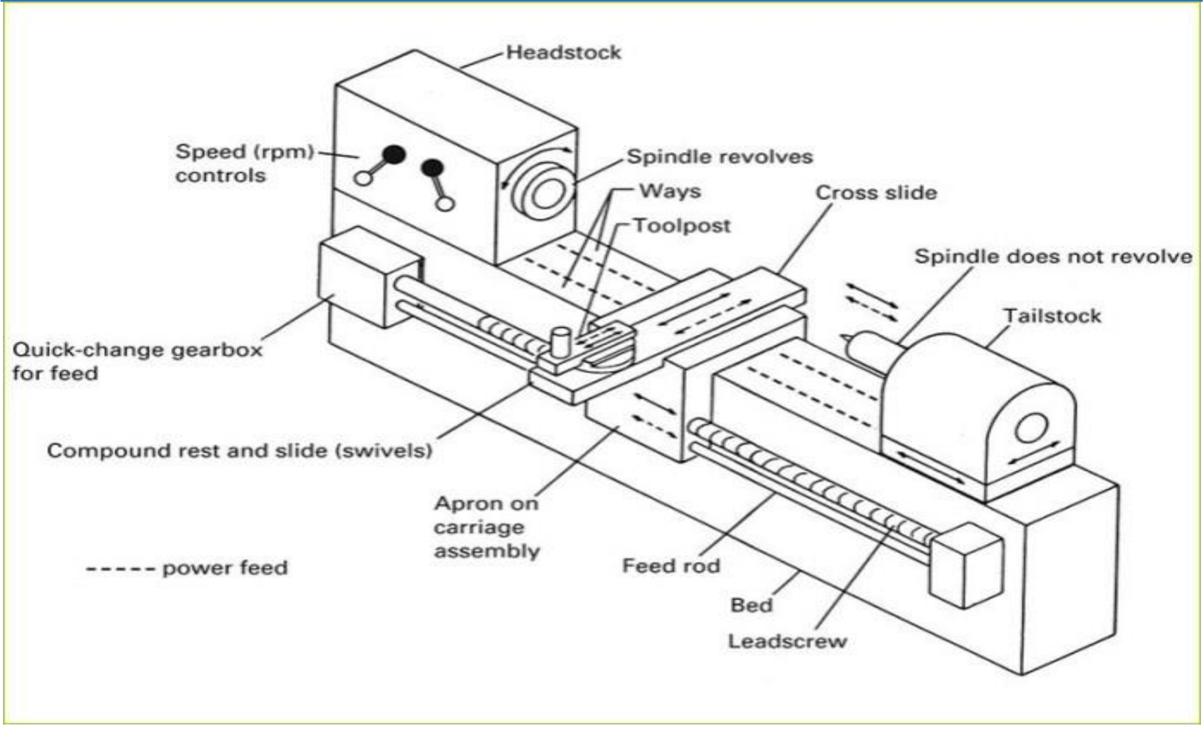


Figure 4. The principal parts of the engine lathe and movements that can be performed on it (Tuleun & Guma, 2006)

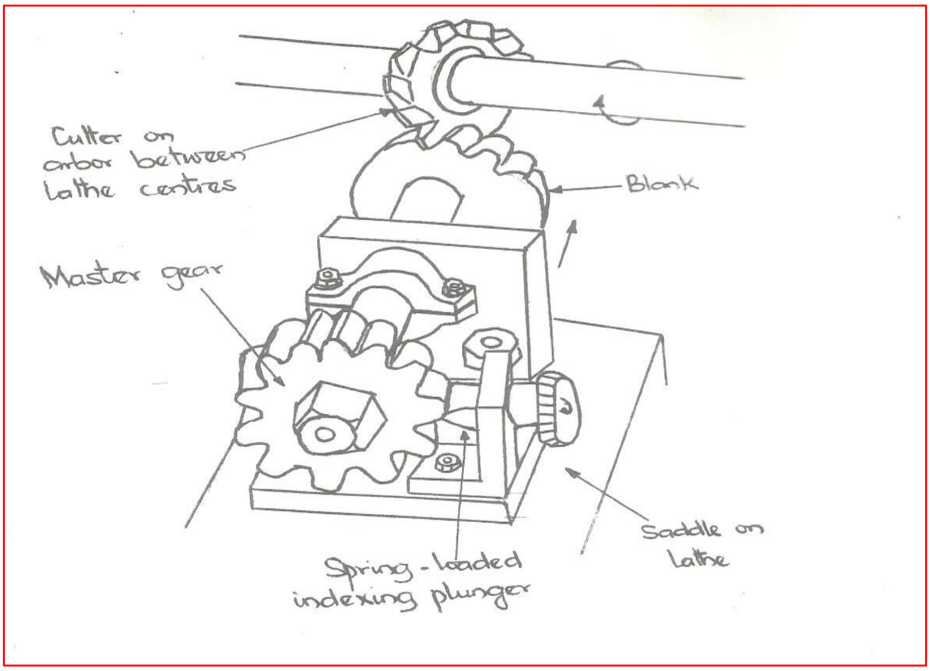


Figure 5a. Arrangement for machining spur gears on the lathe using an attachment (Amadi, 1996)

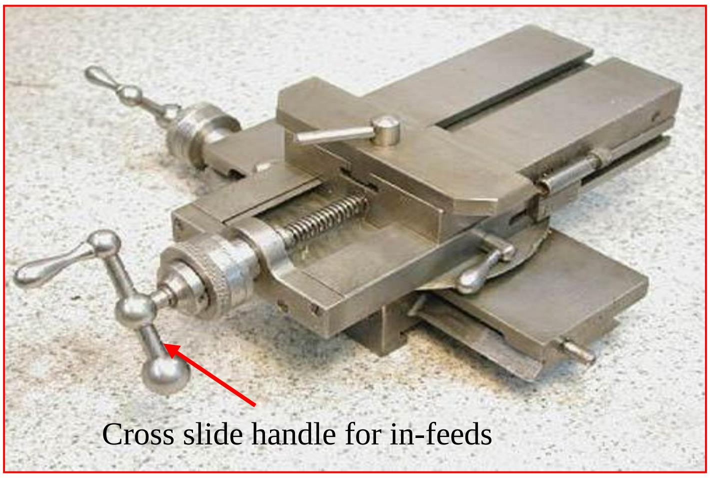


Figure 5b. The lathe cross slide and saddle on which the spur gear machining master is attached (Amadi, 1996)

Possibility of machining bevel gears on the engine lathe

Straight bevel gears have a tooth form which tapers in width and in depth, getting wider and deeper to the outside of the gear. The first step to produce straight bevel gear on the engine lathe would require production of the blank with gear head, and then producing the gear teeth on the gear head. The blank stock can be bored longitudinally-axially to desired specification using conventional drilling and boring operations on the lathe. Most engine lathes are provided with taper turning attachment as an accessory. Taper turning attachment can be used to turn the desired gear blank to tapering specification. A common taper turning attachment for the lathe is shown in Figure 6. The taper turning attachment has a guiding bar that is pivoted as its center as shown in Figure 6. By using bottom plate or bracket the attachment can be attached to the rear end of the lathe bed. The guiding bar has graduations in degrees. The bar can be swung and set in any required angle. The bar also has a guide block which connects to the rear end of the cross slide and it moves on the guide bar. Before connecting to the cross slide, the binder screw is removed, hence the cross slide is free from the cross slide screw.

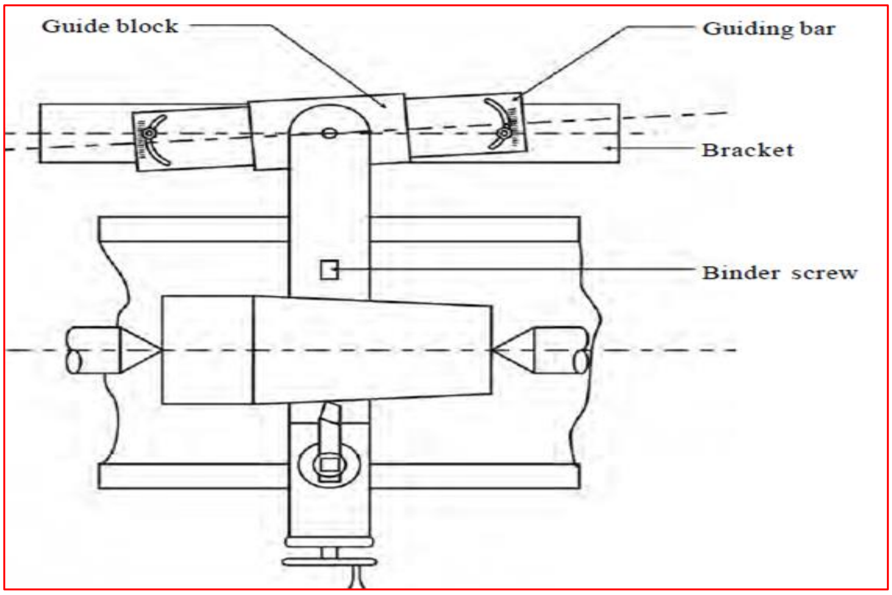


Figure 6. A taper turning attachment for the lathe (Dalvi*et al*, 2017)

After producing the desired blank, the next thing to do is to cut the desired number of teeth on the blank into shape. A suitable milling cutter that can produce the desired tooth width and depth can be selected and used for the cutting. The cutter can be held on an arbor between the lathe centers like the case of spur gear-cutting on the lathe. The blank can be held on the cross slide of the lathe and provided with an indexing mechanism in accordance with the desired number of teeth to be cut on it. However, unlike the case of spur gear-cutting; the blank must be held on the indexable master tilted backward at the gear taper angle in alignment with the cutter for cutting the teeth into desired depth and width by the rotational movement of the selected cutter. This would require slight modification in the design of the indexable master. Specially-shaped gear cutters that are tapered can also be exploited to cut the teeth. From this discussion, it can be appreciated that the essential requirement in cutting straight bevel gear on the lathe is the development of a suitable attachment that can be fastened to lathe especially on the cross slide and holding the gear blank in correct tilting alignment with the cutter for proper cutting of the gear teeth. The attachment must also incorporate a suitable indexing mechanism for indexing the blank in accordance with the desired number of teeth to be cut on the blank.

For the helical or spiral bevel gear it was noted that gear-hobbing is one of the most versatile method of machining spiral bevel gears (Álvarez et al, 2015; Bouzaki *et al*, 2008; Kawasaki, 2010). In gear hobbing the gear blank is held and rotated in rotational kinematic compatibility with the cutter called hob with teeth form and number of teeth the same as the teeth to be produced on the blank. The gear blank is then brought towards the hob to get the desired tooth depth then the rotating hob is pressed against the blank and fed along the face of the gear blank parallel to its axis to form teeth on the blank as shown in Figure 7.

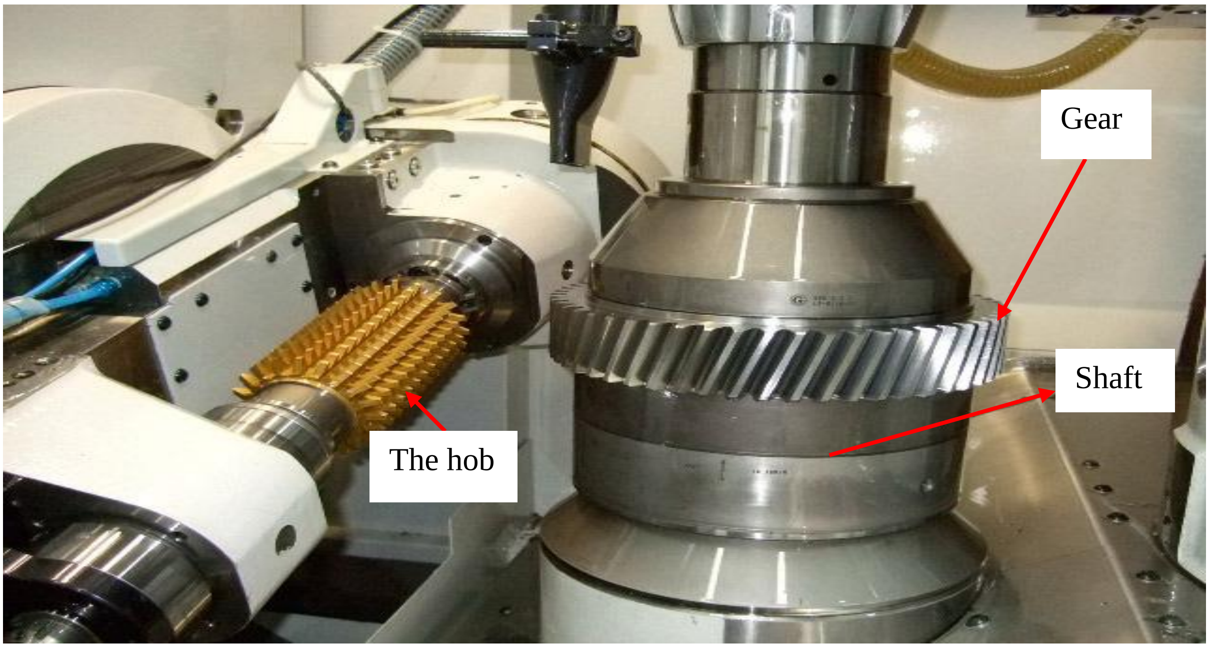


Figure 7. Principle for hobbing spiral bevel gear (Gupta & Laubscher, 2017)

To therefore machine spiral bevel gears on the lathe, the gear hobbing principle can be implemented on the machine tool with suitable hobs and blanks. Technology then demands how this can be done. To accomplish this, it is seen that the hob for producing the desired spiral gear can be held and rotated between the lathe centers on an arbor. The next step is how to hold the cylindrical blank rigidly relative to the hob for forming the gear teeth on the blank. To accomplish this, there will be need to develop a suitable attachment for holding the hob. The gear blank can be held on a vertical rotary cylindrical shaft that can be moved along the longitudinal feed direction of the lathe and the cross slide direction for contacting the blank and forming teeth on the blank. The attachment can be mounted on the cross slide. The blank can be mounted on a designed shaft by keying it to the shaft. The shaft must be properly designed and suitably held in two bearings. The shaft must also be provided wth rotary capability by driving it using the excess power of the lathe or suitable auxillary powered motor.It is also needful that gear blank axis which coincides with the shaft axis is provided with capability to be set at an angle equal to helix angle of the reference gear helix to the axis of the hob to bring the blank teeth in plane of the hob's teeth. The pressing of the hob to the blank can be achieved by a suitably designed springing mechanism.

Conclusion

Bevel gears are complex machinery components used in mechanical engineering which can only be produced on special and costly machines. A survey of the engine lathe as the most versatile and commonly available machine tool in machine shops was conducted to reaffirm its features and production capabilities. A feasibility of producing bevel gears on the lathe to beneficially meet local jobbing and purpose-built needs has been explored. The study shows that both straight and spiral bevel gears can be produced on the lathe. Straight bevel gears can be produced on the lathe with suitably selected milling cutter using prepared bevel blanks and, existing or developed suitable attachment that incorporates indexing mechanism and can get the gear blank properly aligned with the cutter. Spiral bevel gears can also be produced on the lathe by axial hobbing using; developed suitable attachment that incorporates suitable clamping and indexing devices, selected hobbing cutter, and proper size of prepared cylindrical gear blanks. Suitable features of the lathe that can be exploited to develop the required attachments are discussed. The information is hereby put forward for the way forward by concerned engineers and researchers on the subject.

References

Álvarez, A., López de Lacalle, L.N., Olaiz, A., & Rivero, A. (2015). Large spiral bevel gears on universal 5-axis milling machines a complete process. The Manufacturing Engineering Society International Conference, MESIC. doi: 10.1016/j.proeng.2015.12.511

Amadi, C.O. (1996). A Case Study of Machining Bevel Gears on the Lathe. B.Eng Research Project, Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria.

Boral, P., Stoić, A., & Kljajin, M. (2018). Machining of Spur Gears Using a Special Milling Cutter. *Technical Gazette 25*(3), 798-802.

Bouzaki, K.D., Lili, E., Michailidis, N., &Friderikos, O. (2008). Manufacturing of cylindrical gears by generating cutting processes: A critical synthesis of analysis methods. *CIRP Annals – Manufacturing Technology, 57*, 676–696.

Chaphalkar, N. (2013). Economics of Machining Bevel Gears on Multi-Tasking Machines. DMG/Mori Seiki USA, December 11.

Dalvi, V., Jayswal, A., Mistry, P., &Thomas, B. (2017). Lathe Attachment for Gear Manufacturing. *IJARIIE, 3*(2), 3767-3775.

Gadakh, R. S., Londhe, P. G., Shaikh, B. A., & Shaikh, F.S. (2016). Gear Manufacturing by Using Conventional Lathe Machine. *International Journal of Research in Engineering and Technology, 5*(5), 105-110.

Gupta, K., & Laubscher, R. (2017). Chapter 2 – Conventional Manufacturing of Cylindrical Gears. In: *Advanced Gear Manufacturing and Finishing,* 35-51.

Hyatt, G., & Piber, M. A. (2014). Review of New Strategies for Gear Production. CIRP International Conference on High Performance Cutting.

Jain, K.C., &Chitale, A.K. (2014).*Textbook of Production Engineering*. 2nd ed. Kindle Edition.

Kawasaki, K. (2010). Manufacturing method for large-sized bevel gears in cyclo-palloid system using multi-axis control and multi-tasking machine tool. Proceedings of international conference on gears, Munich, Germany.

Li, L., Zhang, L., Yu, B., Wang, K., & Liu, F. (2017). An efficient spur gear shaping method based on homogenizing cutting area through variational circular feed rate. Proceedings of the Institution of Mechanical Engineers, Part B. *Journal of Engineering Manufacture, 23*(9), 1587-1598.

Pushpalatha, P., Suresh, G., Balaji, K., & Babu, P.K. (2018). Spur Gear Cutting Attachment for Lathe Machine: A Key to Increased Productivity, Decreased Cost, and Floor Area Requirement. *International Journal of Emerging Engineering Research and Technology*, *6*(7), 18-24.

Shewale, S.V., & Suryawanshi, S.R. (2016). Analysis of Process Parameters in Hobbing using Optimization Technique. 2nd International Conferenceon Advances in Mechanical Engineering Amrutvahini College of Engineering, Sangamner, India. *International Advanced Research Journal in Science, Engineering and Technology, 3*(Special Issue 1), 273-276.

Tuleun, L.T., & Guma, T.N. (2006). Development of a Non-circular Boring Attachment for the Lathe. *Ife Journal of Technology, 15*(1), 51-56.