Chapter -1

INTRODUCTION

Boring is the process of enlarging a hole which is pre-drilled or pre-casted. Boring is used to achieve the close tolerances and good surface finish. Boring produces an internal cylindrical surface. Generally, one begins with a cylindrical work-piece of some nominal inner diameter that must be bored out to a larger diameter of specified tolerance. Boring is an important process in the automotive, chemical, foundry industries. A typical boring operation produces parts, which have critical features requiring a specified surface roughness. Applications include: boring of piston bore, valve holes, bearings races and many more.

1.1 Mechanics of Boring Process:
Boring can be considered as a counter part of turning process which cuts the external diameter. It is a single point cutting operation. Boring bars are used to carry out the boring operation. Figure 1 shows the mechanics of boring process.

![Fig. 1 Mechanics of Boring Process](image)

During the boring operation the boring bar is fed in the feed direction at a specific cutting depth and a specific rotational speed of the work-piece. During an internal turning operation the cutting tool and the boring bar are subjected to cutting forces viz. tangential force, radial force and axial force due to the relative motion between the tool and work-piece in the cutting speed direction and in the feed direction. A desire of being able to perform a cutting operation into pre-drilled holes in a work-piece limits the diameter or cross sectional size of the boring bar.
1.2 Surface Roughness and its Measurement:

Surface roughness refers to the deviation from the nominal surface. Surface roughness is an important attribute of the job quality. The surface finish has a great effect on the functioning of the two mating parts as reasonably good surface finish can improve the tribological properties, fatigue strength, corrosion resistance as well as look of the product. High quality of surface finish can cause the production cost to increase and hence it is recommended to estimate the correct value of surface finish after looking at the functional aspect of the part. Surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. It describes the geometry of the machined surfaces combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependent. Figure 2 shows the typical surface roughness profile.

![Surface Roughness Profile](image)

- **Y**: Profile curve
- **X**: Profile direction
- **Z**: Average roughness height
- **L**: Sampling length
- **H**: Profile height

**Fig.2** Surface Roughness Profile

Surface finish in boring is the function of the various factors such as speed, feed, depth of cut, work piece material, tool geometry, work hardness, tool nose radius, stability of machine tools, cutting fluids and many more. Variations in the texture of a critical surface of a part influence its ability to resist wear and fatigue; to assist or destroy effective
lubrication; to increase or decrease its friction and/or abrasive action on other parts, and to resist corrosion, as well as affect many other properties that may be critical under certain conditions. The Surface texture can be designated as Surface Roughness and Waviness. Surface roughness is the primary irregularities and a prominent variation in the surface texture with considerably higher amplitude and of smaller wavelengths. Waviness refers to the secondary irregularities upon which roughness is superimposed, which are of significantly longer wavelength and are usually caused by machine or work deflections, tool or work-piece vibration, heat treatment, or warping.

The surface roughness is usually expressed as roughness average (Ra) which is the arithmetic average of the height of the roughness irregularities above the mean line along the sampling length L. The value of Ra is normally measured in the microns in the metric system. The following equation gives the value of Ra over the sampling length L.

\[
Ra = \frac{1}{L} \int_0^L z(x) \, dx
\]

Where z is the height of irregularity along the length x.

Surface roughness of the bored surfaces is usually measured off-line by using the stylus methods. Rapid changes in the complexity and precision requirements of mechanical products have created a need for improved methods of determining, designating, producing, and controlling the surface texture of manufactured parts. Although standards are aimed at standardizing methods for measuring by using stylus probes and electronic transducers for surface quality control, other descriptive specifications are sometimes required, i.e., interferometric light bands, peak-to-valley by optical sectioning, light reflectance by commercial gloss-meters, etc. The precise definition and measurement of surface texture irregularities of machined surfaces are almost impossible because the irregularities are very complex in shape and character and, being so small; do not lend themselves to direct measurement. Although both their shape and length may affect their properties, control of their average height and direction usually provides sufficient control of their performance.
The traditional way to monitor the surface quality of a machined part is to measure the surface roughness by using a surface gauge. The most used surface gauge is the stylus type surface gauge. It has a diamond stylus dragging along the test surface, of which, the up and down movement is recorded and calculated for the surface roughness. Since this measuring method requires that the stylus have direct contact to the measured surface, measurement cannot be conducted unless the test surface is in a stationary mode. In other words, the stylus measuring method cannot be applied to an in-process work piece on a lathe when the work piece is spinning.

Other measurement techniques must be used to obtain in-process surface roughness in turning operations. Since there is no actual in-process measuring available, the surface roughness is predicted by the use of other technologies, such as optical, acoustic, electromagnetic, force, and vibration. However, the optical, acoustic, and electromagnetic technologies are not practical in the machining environment because chips and coolant interfere with the travel of these signals. Cutting force and machining vibration can be used to predict the surface roughness of a machined surface. Practically, a dynamometer (the force sensor) is expensive and difficult to mount to a lathe. On the other hand, an accelerometer is comparatively inexpensive and easy to mount. Therefore, an accelerometer has the potential to be applied in collecting vibration information for the prediction of a machined surface.

Even though there have been lot many advances in the techniques to measure the surface roughness with greater accuracy but in process measurement of surface roughness is still a challenge to the quality control engineers as it’s difficult to measure the surface roughness during the machining. In all the present practices to measure the surface roughness of the work-piece the machining has to stop, the work-piece has to be removed from the work-holding device which ultimately increases the non-productive time. Hence there is a need to find out some direct or indirect technique to evaluate the surface roughness when the metal cutting process is in progress.
1.3 Material Removal Rate (MRR) in Boring Process:

Material removal rate (MRR) is the rate at which the volume of the material cut per unit time. It is usually expressed as cubic meter per minute. Material removal rate indirectly decides the machining time required for machining cycle. Higher values of material removal rate are always preferred as its results in minimizing the machining time and hence enhancing the productivity.

Material removal rate is the direct function of machining parameters viz. speed, feed and depth of cut. Maximizing the values of these parameters during machining will ultimately enhance the material removal rate. Maximizing the material removal rate however has several adverse effects. Excessive material removal rate causes poor surface finish, high tool wear, tool vibrations, excessive heat generation during machining, deformation of the tool and work-piece. Research in the area of tooling and manufacturing technologies has now a days made it possible to use higher rate of material removal. The material removal rate in boring can be given by following expression.

\[
\text{Material Removal Rate (m}^3/\text{min)} = \pi \times D \times f \times \text{DOC}
\]

Where D is the inside diameter (meter) of the work-piece, f is the feed expressed in meter per minute and DOC is the depth of cut in meter.

Boring process is usually a semi-finish or finish process where comparatively lower value of speed, feed and depth of cuts are employed. Material removal rate in boring process is therefore less as compared to that exists in multi-tooth cutter machining processes like milling drilling, reaming and many more. Maximizing the values of machining parameters in order to maximize the material removal rate therefore always result in poor surface finish which need to be taken care of.

1.4 Machining Time in Boring Process:

Boring is a multi-pass operation in which the final dimension is achieved through cutting the material through several steps. The total time required is the addition of the time required for each cycle of machining. The cost of machining is the direct function of the
machining time. Maximizing the material removal rate tends to reduce the machining time.

1.5 Machining Parameters affecting Boring Process:

Boring is one of the most important and commonly found machining process irrespective of the type of industry. Various parameters pertaining to properties of the materials of job and tool, geometry of tool and job, machining parameters like speed, feed and depth of cut, coolant flow, tool vibrations, machine condition and many more have their direct and indirect effect on the material removal rate in the boring process.

In the job production systems all above parameters are frequently changes as each job requires different set-up and machining conditions. On contrast, in mass production system it can been seen that all above parameters except machining parameters does not change as the job to be machined does not change. Thus in mass production system controlling of machining parameters will help to control the material removal rate and hence machining time.

1.6 Optimization of Machining Parameters:

Optimization refers to the process of finding the values of the variables affecting a process subjected to the particular constraints. In the boring process like other processes, it is always recommended to set the machining parameters to higher values so as to maximize the material removal rate in order to reduce the machining time.

But at the same time, maximizing the values of machining parameters may result in generating the poor surface finish which must be taken care. Thus for the boring process the values of the machining parameters should be decided based on the value of surface roughness required. It is therefore possible to find the values of machining parameters which will result in maximum material removal rate by maintaining required value of surface finish.
1.7 Boring Bar Vibrations and its control:

The vibration problem in metal cutting has a considerable influence on important factors such as productivity, production costs, etc. Turning operations, and especially boring operations, are facing tough vibration related problems. The actual cutting is performed at the cutting tool mounted at the tip of the boring bar. The cutting process seems to be a time varying process and contains non-stationary as well as nonlinear parameters that are not under control. The experiments showed that the vibrations were usually dominated by the first resonance frequency in either of the two directions of the boring bar.

During a cutting operation the boring bar is fed in the feed direction at a specific cutting depth and a specific rotational speed of the work-piece. The vibration of the boring bar is influenced by three parameters viz. feed rate, cutting depth and cutting speed. The vibrations in the boring bar are in the cutting speed and the cutting depth direction. Usually a boring bar is comparatively long and slender, and is thereby more sensitive to excitation forces. The boring bar motion may vary with time. The dynamic motion originates from the deformation process of the work material. The vibrational motion of the boring bar will affect the result of the machining, and the surface finish in particular. The tool life is also likely to be influenced by the vibrations. The term “Chatter” is often used instead of vibration in the cutting process.

Vibrations found in boring process can be classified as forced and self excited vibrations. Forced vibrations are the result of many parameters namely rigidity of the machine tool, irregularities in the material of work-piece, internal flaws or even non-circularity of the job. Due these reasons the boring bar during every cycle is subjected to the dynamic cutting force which induces the vibrations. Self excited vibrations are caused because of the machining process itself like variation of rake angle due to formation of built-up edge, deflection of the boring bar in axial direction, variation in micro-hardness of work-piece material.

The forces generated when the tool and work-piece come into contact produce significant structural deflections. Regenerative chatter is the result of the unstable interaction between the cutting forces and the machine tool-work-piece structures, and may result in excessive forces and tool wear, tool failure, and scrap parts due to
unacceptable surface finish. The feed force for an orthogonal cutting process (e.g., turning and boring) is typically described as [39]:

\[ F(t) = K \dot{d} [f_n + x(t) - x(t - \tau)] \]

Where \( f_n \) is the nominal feed, \( x \) is the displacement of the tool in the feed direction, and \( \tau \) is the time for one tool revolution. The assumption is that the work-piece is much more rigid than the tool and the force is proportional to the instantaneous feed and the depth-of-cut, and does not explicitly depend upon the cutting speed. The instantaneous chip load is a function of the nominal feed as well as the current tool displacement and the tool displacement at the previous tool revolution. Assuming a simple model, the vibration of the tool structure may be described by

\[ m \ddot{x}(t) + c \dot{x}(t) + kx(t) = F(t) \]

Where \( m \), \( c \), and \( k \) are the effective mass, damping, and stiffness, respectively, of the tool structure.

Tool vibrations can be controlled by controlling the magnitude of dynamic cutting force which in turn depends on the machining conditions. Controlling the machining variables like spindle speed, feed, depth of cut and many more will help to control the boring bar vibrations which is one of the important cause for generating the surface texture.

1.8 On-line Monitoring and Control of Manufacturing Processes:

The continuous demand for higher productivity, product quality and automation asks for better understanding and control of the machining process. A better understanding can be achieved through experimental measurement and theoretical simulations and modeling of the process and its resulting product. In particular process monitoring and control is desirable for automated control and optimization of the process and in turn of productivity and product quality. However, due to the high complexity of the process, in particular of the complex interaction system/process/product, the above goals have only partially been achieved today, to a limited, unsatisfactory extent. High-level machine tool controls for process automation are intended to maximize material
removal while at the same time minimizing tool wear or failure to maintain part quality specifications. To this end, reliable sensors are required to identify the behaviors of the machine, tool, and work. Various machine tool sensors have been developed for the monitoring of tool wear and failure, part dimensions, surface roughness, surface burn, chatter onset, etc.

Manufacturing processes are governed by number of parameters which need to be controlled. Process automation holds the promise of bridging the gap between product design and process planning. It is still a dream of manufacturing industry to have a man-less factory. Monitoring the variables of interest and controlling them by controlling the relevant parameters is still a challenge to the researchers.

Process control which is not commonly integrated in today’s machine tool is the automatic adjustment of the process parameters viz. speed, feed, depth of cut and many more in order to increase the productivity and part quality. Various parameters pertaining to the machining process and work-piece needs to be measured during the machining. Many researchers have tried to measure the product quality parameters like surface finish, dimensional deviation during the machining along with various factors involved in the metal cutting like cutting forces, tool wear, tool temperature, tool deformation and many more during the machining process. An attempt has been made to correlate these parameters with each other. Machining processes like turning, milling, grinding, drilling have been considered for such type of study. Boring is however an unattended process which need to be considered for such type of study.