Chapter 2

LITERATURE SURVEY

Literature survey was carried out considering the various aspects.

2.1 Overview:

Various techniques employed for the measurement of surface roughness by the experts are discussed in the section 2.2. Comparative analysis of various techniques studied will be helpful for selection of the suitable method for measurement of surface roughness during particular application.

Nature of vibrations pertaining to the boring bar and details of chatter phenomena is discussed in section 2.3. Research work related to the analysis of boring bar vibrations has been summarized in detail.

Boring bar vibrations is the effect of various directly and indirectly affecting parameters. In section 2.4, the research related to the relation between machining parameters on boring bar vibrations are discussed in detail.

The literature available on effect of boring bar vibrations on generation of surface roughness is discussed in section 2.5.

2.2 Surface Roughness and its Evaluation:

Surface roughness is widely used parameter to describe the nature of surface texture generated during the machining. Evaluation of surface roughness is very important in machining as it’s having direct relevance to the various properties of the surface like friction, fatigue, electrical and thermal contact resistance, appearance and many more. Poor surface finish is basically due to the three basic phenomena: (i) the tool geometry and the kinematics relative to the parts- feed marks (ii) self excited and machine tool vibrations (iii) surface plastic deformation which occurs due to worn tool, built-up edge and material softening which is due to high temperature or insufficient cooling.
Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controllable and some cannot. Controllable parameters includes feed, speed, tool geometry and tool set-up while the parameters like tool, work-piece and machine vibrations, material properties variability exhibit the random trend and found difficult to be control.

There have been several efforts made so far to develop the various techniques for measurement the surface roughness directly or indirectly with the help of different transducers. The stylus profilometry [1] is the fundamental and most reliable way of measuring the surface roughness where the probe or diamond tracer follows the irregularities of the surface and produces an equivalent electrical signal. The arrangement is shown in figure 3. Now a days there have been lot many developments in probe type surface recorders which records the movement of the probe at extremely small level and produces the results in the various forms. The major problem of this technique is the long period of time needed to scan the larger areas, used off-line and cannot be used for non-flat surfaces. The in-process surface roughness measurement is one of the most difficult problem in metrology. Research work on the elaboration of various methods and devices for on-line monitoring of surface roughness has been continued over the last twenty five years, but yet no effective and general purpose technique has been developed so far. Grzesik [2] used the minimum undeformed chip thickness for predicting the surface finish in turning operation. The approach was developed based on the assumption that the deviation of actual surface roughness from predicted was because of the adhesiveness found between tool-work-piece interfaces.

Acoustic Emission (AE) analysis was demonstrated by C. Beggan et. al. [3] to predict the surface roughness in turning. Acoustic emissions which are nothing but transient elastic waves were found to be the result of rapid release of energy due to several causes. The source of this energy can be due to chip formation, due to friction between cutting edge of tool and chip and may be due to friction between cutting tool flank and work-piece.
An ultrasonic system was developed by S.A. Coker et.al. [4] in which an ultrasonic sensor was used to send the pulses which will be reflected by the surface of the work piece. The magnitude of reflected signal was then calibrated with the measured value of surface roughness using profilometer. The correlation between surface roughness value by this technique and by profilometry is shown in Fig.3. This technique was found to be useful as the chip flow and coolant does not have any effect on the ultrasonic signal. But the noise from other sources when mixed with the ultrasonic waves gives the faulty readings. So this technique is not found reliable for in-process gauging of the surface roughness.

The fringe field capacitive (FFC) method was introduced by B. Nowicki and A. Jarkiewicz [5] for in process measurement of surface roughness in grinding process. During the study they found that the measuring signal obtained from FFC based devices for the measurement system is the direct function of the average height of the roughness.

The capacitance method enables the in-process control of the surfaces between 0 and 1 micron. The technique developed is not sensitive to the type of material and flow of coolant. This method however is suitable for the low average roughness values as for the higher values the errors up to 25% was observed which is not tolerable in a finishing process like boring.

Luk et.al. [6] found the vision system to predict the surface roughness value. They have used the frequency to convert the image data into spatial frequency which was then correlated to surface roughness by using least square method. This method however was not so efficient when used for in-process prediction of the surface roughness due to difficulty in capturing of the image during rotation of the job.

Shiraishi and Sata [7] used a laser based shadow graph sensor for directly measuring the surface roughness. A laser beam was focused on the edge profile of the surface and an image was created. This method was found to be suitable for surface roughness value about 10 microns or more and not suitable for lower values of surface roughness due to reflection problem.
Interferometers techniques employing fringe pattern projection and image analysis were also attempted by Salisbury et.al. [8]. But it was not found to be useful for in-process or in-cycle measurement. They have used the digital wave front interferometers and nano-surface topology. A capacitive sensor to measure the roughness between 1 to 5 microns with a scanning rate of 100 mm/s was employed by Garbini et.al. [9] in which a capacitive sensor put in capacitive electrode work as one electrode while the work-piece was made a second electrode. The variation in surface roughness was estimated as the change in capacitance between these two electrodes. Spurgeon and Slater [10] and Lin et.al. [11] used the fiber bundle to deliver the light to surface and to collect the reflected light and guide it to a photo-detector as shown in Fig. 4. A correlation was found between the intensity of the reflected light and the average surface roughness value. This method did not find useful as the different material surfaces reflects different light for same value of surface finish.

Fig. 3  Correlation between Ultrasonic and Profilometer surface roughness [4]
This technique was found to be suitable only for roughness value up to 0.5 microns. To avoid the problem of reflection, North and Agarwal [12] used the two bundles of fiber optics which focuses on surface at two angles of incidence. These found a good agreement with profilometry readings.

Machine vision system was employed by Luk F. [13], Gupta M.[14] and Wang et.al. [15] for prediction of surface roughness which was characterized by frequency distribution of grey level occurrence in a scattered light intensity image. The correlation is shown in the Fig. 5. The image was obtained by using CCD camera and scattered light frequency distribution which is the histogram of light scattering intensity was obtained.

Considering the state-of-art technology pertaining to the on-line measurement it can be concluded that even though there have been several efforts made to evaluate the value of surface roughness during the metal is being cut, the production engineers are still looking for a more robust, simple but accurate way of measuring the in-process surface roughness.

**Fig. 4** Laser light and sensor arrangement for surface roughness prediction [11]
There have been few efforts made to investigate the surface roughness by monitoring the tool vibrations. Jang et.al. [16] have considered the turning process for such analysis. Boring process even though considered to be similar to turning process, differs from turning because of the orientation of the tool and directions of the cutting forces to which the tool is subjected. Benardos, P.G.and G.C. Vosniakos [17] presented a review of various techniques employed for the prediction of surface roughness in machining.

The boring process however still remains an un-attended process for such type of investigation. In the present work an attempt was made to monitor the surface roughness by monitoring the tool vibrations using accelerometers mounted on the tool in close vicinity of the cutting tip. The correlation between tool vibrations and surface roughness was investigated which later on used for on-line control of surface roughness in order to maximize the material removal rate to enhance the productivity.
2.3 Boring bar vibrations and chatter:

Turning and boring both are the single point cutting operation. Turning is used to remove the material for the outer surface of an axisymmetric work piece. Boring is used to enlarge the existing holes. The static forces generated are the time variant in both the processes because of the fixed cutting edge of the tool. Moreover the static forces are identical when the same cutting conditions are applied in both the processes. If the dynamic properties are compared, they are dissimilar due to different flexibilities of the structures.

![Fig 6. Single point cutting processes (a) Turning (b) Boring](image)

Literature surveys carried out in order to study the tool vibrations have considered both the processes due to their similarity. A number of experimental and analytical studies have been carried out on tool vibrations in boring. Most research has been carried out on dynamic modeling of cutting dynamics and usually concentrates on the prediction of stability limits as well as experimental methods for the estimation of model parameters related to the structural dynamic properties of the machine tool, the work-piece material, etc.

Tlusty [18] investigated and summarized some of the research that has been done on cutting dynamics with respect to regenerative chatter based on dynamic cutting force coefficient data (DCFC). An analytical model of cutting dynamics for orthogonal cutting
has been developed by Wu and Liu [19, 20]. It was derived from a two-degrees-of-freedom “pseudo-static geometric configuration” of the cutting process by including the dynamic fluctuations of the friction coefficient for the tool rake face when responding to variation of the relative speed of the tool–chip interface. Minis et al. [21-23] derived a linear model of cutting dynamics in turning based on frequency response functions; this described the structural dynamics of the cutting point and a modified CIRP model for the cutting process dynamics where the DCFC was replaced by frequency response functions. Pandit et al. [24, 25] modeled tool chatter in turning based on a parametric time-series approach using experimental data for tool vibration. The experimental chatter data were described with the aid of an ARMA model driven by white noise. Kalmar-Nagy et al. [26] use a non-linear one-degree-of-freedom based delay-differential equation model of regenerative machine tool vibration to show the existence of a sub-critical bifurcation.

Gradisek et al. [27] analyzed a non-linear two-degree-of-freedom based model of non-regenerative orthogonal cutting. A subset of the research on cutting dynamics has focused on boring dynamics. Parker [28] investigated experimentally the stability limit of a slender boring bar in external longitudinal turning for regenerative cutting conditions at different cutting speeds and inclination angles. The vibrations were measured in the cutting speed and cutting depth direction. He developed a two-degrees-of-freedom analytical model of the boring bar with two input forces, one proportional to the variation of chip thickness and the other proportional to the penetration velocity. Stability limits were predicted with the aid of the model; these were then compared with the experimental results. However, there was a wide range of cutting speeds resulting in extensive vibration in the cutting speed direction, which was not predicted by the model. The experimental results indicate that the direction of vibration is either in the cutting speed direction or in between the cutting speed and cutting depth direction. Zhang and Kapoor [29] developed an analytical model of boring dynamics. This was derived from a two-degrees-of-freedom model of a clamped boring bar and a dynamic cutting force model based on four cutting force components. Using their analytical model based on the estimated parameters, Zhang et al. predicted the limit width of cut (cutting stiffness). By means of experiments they determined the stability limit for a boring bar in an external
thread cutting process and compared it with the predicted width. They claimed that the predicted and experimental stability limits correlated fairly well. Rao et al. [30] introduced an analytical dynamic boring force model which includes the instantaneous variation of chip cross-sectional area under dynamic conditions. They produced a continuous system model of boring dynamics based on their dynamic boring force model and a uniform Euler–Bernoulli cantilever beam with circular cross-section. They studied boring with a zero-side cutting-edge angle and calculated chatter frequencies (fundamental Eigen frequency of the boring bar) and amplitudes; these were then compared with the experimental results. They claim that their model correlates well with the experimental results. Kuster [31] developed a computer simulation model of boring bar dynamics based on a three dimensional model of regenerative cutting. Using the knowledge of the radius of curvature of the cutting tool tip as a base, their model differentiates between roughing and finishing in boring. Compared with experimentally obtained stability boundaries in boring they claimed that estimates of stability boundaries produced by their model correlate well.

Jayaram and Iyer [32] attempted to model the chatter stability limit in boring. They used a simplified analytical model of boring bar dynamics based on direct point receptances and a linear regenerative cutting force model for three orthogonal directions. They used experimentally determined stability limits for turning to validate their model. An advanced time domain model of boring bar dynamics was developed by Lazoglu et al. [33]. The model is based on a modular form including; a work-piece geometry and surface topography module, a kinematics and tool position module, a dynamic chip load module, a dynamic cutting force prediction module and a structural dynamics module. Using the cutting process parameters, tool and work-piece geometries and the modal parameters as inputs the model produces estimates of cutting forces and vibrations versus time as well as machined work-piece topography. They conducted boring experiments in which the feed, tangential and radial cutting forces were measured as well as the machined work-piece topography. Measured force records and work piece topography records were compared with corresponding forces and surfaces produced by their model.

However, there are relatively few works which address the identification of dynamic properties of machine tool vibration. Khraisheh et al. [34] investigated primary
chatter (non-regenerative chatter) in external thread and slot cutting processes based on a time-series approach which uses experimental data from both tool vibration and corresponding cutting forces. They used the wavelet transform to study the dynamical characteristics and frequency content of the cutting process. Also, they examined the existence of chaotic behavior in the cutting process by using methods such as the phase plane, poin-carle map, and fractal dimensions. Based on the results of the wavelet transform, they concluded that the cutting process undergoes non-linear effects and that the tool motion is chaotic. Furthermore, they claimed that both the built-up edge and transient boundary of the tool can be identified by the wavelet transform.

Sturesson et al. [35] investigated tool vibration or chatter in external longitudinal turning based on a time-series approach which uses experimental data from tool vibration and a normal mode analysis. They examined the statistical properties of the tool vibration by using stationarity tests, Gaussianity test (Chi-square goodness-of-fit test), correlation function estimates and spectral density estimates of the tool vibration. Based on an FEM-model of the tool holder—clamping structure they estimated the Eigen frequencies of the tool holder shank. Their statistical analysis showed that tool vibration in external longitudinal turning usually has wide-sense stationary statistical properties and that the vibrations are usually Gaussian distributed. They also pointed out that the occasional non-Gaussian distributed tool vibration may indicate non-linear response of the tool holder. They observed that in different work-piece materials the bandwidth as well as the maximum peak of spectral densities of tool vibration differed. They state that the Eigen frequencies from the normal mode analysis correlate well with the location of the peaks in the spectral densities and that a narrowband multiple-degree-of-freedom model is adequate for describing the dynamic behavior of the machine tool system. Using experimental data,

Gradisek et al. [36] examined whether the transition from chatter-free cutting to chatter resembles the bifurcation. Based on estimates of the Fokker–Plank equations drift coefficient they analyzed three regimes of turning: chatter-free cutting, cutting accompanied by a strong chatter and cutting accompanied by weak chatter. Furthermore, deterministic solutions of the Langevin equation were estimated using the measured data.
and the estimated drift coefficient. They argued that cutting force vibrations during chatter-free cutting can be described as stochastic fluctuations around a stable fix point, while vibrations during the two chatter regimes represent fluctuations around a stable limit cycle. Quantitative characterization of stability of the fix point showed that the latter was stable during chatter-free cutting and unstable during chatter regimes. On the basis of their results they concluded that the transition does exhibits some properties typical of a bifurcation. But they also pointed out that it is not possible to claim that the transition from chatter-free cutting to chatter represents a bifurcation.

Marui et al. [37] investigated primary chatter of boring bars (with a rectangular cross-section) and a tool holder shank experimentally in which they cut the top of a square thread in external longitudinal turning operations. The vibration of the boring bar was measured in both the cutting speed and cutting depth direction. With respect to the tool holder shank, both the cutting force and the displacement were measured in the cutting speed direction. Marui et al. used displacement and force as a function of time and chatter mark on the work-piece. They found that the vibration of the tool was dominated by the motion in the cutting speed direction. The frequency of this self-excited vibration was slightly lower than the first natural frequency in the cutting speed direction of both the boring bars and the tool holder shank.

When boring bars are slender and long, the process is constrained by excessive tool deflections or dynamic vibrations. The tool nose radius and the vibrations, both are detrimental to the accuracy and variation of oblique angle along the cutting, results in the surface finish of the hole, as well as causing accelerated non-uniform distribution of chip thickness and wear and chipping of the tool. Several efforts were made for investigation of cutting forces in boring operation. Robert G. Landers [38] have reported that the forces generated when cutting tool and part come into contact produce significant structural deflections. These structural deflections modulate the chip thickness that, in turn, changes the machining forces which results in tool vibrations.

N.Z. Yussefian et al. [39] have reported that tool deflections or vibrations change the true process parameters. The cutting forces of boring process is prerequisite for selecting appropriate cutting conditions and also preserving process accuracy by avoiding
excessive tool deflections or dynamic vibrations. Young et al. [40] defined an equivalent cutting edge at the intersection of the plane normal to the chip flow direction and the rake face plane. This equivalent cutting edge was then used for cutting force computation. Although good agreement was reported between measured and predicted cutting force components, the proposed approach was confined to the tools with zero rake and inclination angles. Some researchers have studied the cutting force and the process behavior from the micro-point of view. Grum and Kisin [41, 42] investigated the influence of microstructure of the work-piece material on cutting force amplitudes. Several researchers have tried to predict the chip flow angle for machining with oblique nose radius tools [43, 44]. The chip flow angle on the rake face of the tool is an important parameter for chip control and chip curl. It is also a significant geometrical factor affecting the mechanics of cutting. In orthogonal cutting, chip flows perpendicular to the cutting edge and therefore, the chip flow angle is zero, but in oblique cutting due to the three dimensional behavior of cutting process the direction of chip flow is non-zero.

2.4. Machining Parameters and Surface Roughness:

Surface finish in boring is found to be 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. Many researchers have studied the effect of these parameters on the surface finish. Albrecht [45] has investigated the effect of speed, feed, depth of cut and tool nose radius on the surface finish of the steel components. In the present work, a similar attempt was made to find the influence of cutting parameters on surface finish. The results obtained during study are in good agreement with those obtained by others. Ansell and Taylor [46] have investigated the effect of tool material on the surface finish of the cast iron components. The effect of varying cutting speed on the surface finish due to formation of the built-up edge is investigated by Cook and Chandiramani [47]. Lambert [48] has studied the effect of speed, feed, depth of cut, cutting time and tool coating and used multiple regression technique to develop mathematical model. The effect of machining parameters like speed, feed, tool nose radius and depth of cut on surface finish has been studied by Takeyama.
and Ono [49]. The higher values of the speed gives better surface finish for the other parameters to be constant has proved through the experiments by Nassirpour and Wu [50]. The results obtained in the present work also exhibit the similar trend in case of spindle speed as mentioned by other experts through their experimental studies.

Figure 7 shows the generation of surface profile with the movement of the tool in feed direction. Sundaram et.al. [51] have studied the effect of speed, feed, depth of cut, cutting time and tool coating and used multiple regression technique to develop mathematical model. Similar kind of study has been carried out by Mital and Mehta [52] in which they developed the surface finish prediction model as a function of cutting parameters for each individual metal. They have generated the surface finish data for aluminum alloy 390, ductile cast iron, medium carbon leaded steel 4130 and Inconel 718 alloy for a wide range of machining conditions.

In the work carried out here, the effect of cutting parameters viz. spindle speed, feed and depth of cut on surface roughness in boring operation was given through an equation using multiple regression method. The influence of an individual cutting parameter on surface roughness was found to be similar as observed by others during their study.

Fig. 7 Generation of surface profile with the feed of tool marks [17]

Y. Beauchamp et.al. [53] investigated the effect of cutting parameters in dry turning on lathe using full factorial design. Six cutting parameters viz. cutting speed, feed, depth of
cut, tool nose radius, tool length and type of boring bar (un-damped and damped) were considered for the analysis. They found that use of short length tool always results in achieving good quality of surface finish which was also observed during the study presented here. Variations of cutting parameters however have moderate effect on generation of surface texture. Results were measured for un-damped and damped boring bar. Use of damped boring bar results in better surface finish.

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 and combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependent. To select the cutting parameters properly, several mathematical models [54–58] based on statistical regression or neural network techniques have been constructed to establish the relationship between the cutting performance and cutting parameters. Then, an objective function with constraints is formulated to solve the optimal cutting parameters using optimization techniques. Therefore, considerable knowledge and experience are required for this approach. In this study, an alternative approach based on the Taguchi method [59] is used to determine the desired cutting parameters more efficiency. Similar attempt was made the present work to investigate the optimum combination of machining parameters to obtain the desired value of surface finish.

There are some alternative ways for assessing the effects of machining parameters on the surface finish. Comparing the effects of a particular combination of a speed and feed on the surface quality with a different combination of speed and feed brings into play a hidden effect in terms of changed machine dynamics caused due to the difference in surface speeds. This suggests that one needs to fix the dynamic characteristic of the machine (i.e., having a fixed vibration amplitude and frequency at a particular surface speed), before analyzing the rest of the parameters’ effects on surface quality. Thus, changing speeds cause a difference in the vibration dynamics of the machine which remains constant as long as the surface speed remains constant. However, at a constant fixed speed, changing feed rates create differences in surface quality, and these differences can be attributed predominantly if not completely to changing feed rates.
This reasoning is validated by the results from a number of independent studies where a variety of methods were used to predict and measure surface roughness values. In all of these studies, the dominance of feed, which was also observed in the work carried out here on the surface roughness over other machining parameters, is reiterated. Abdullah, A.B., L.Y. Chia, Z. Samad [60] analyzed the effect of feed rate and cutting speed to surface roughness. They concluded, as found in present work that feed is dominating over the spindle speed in generating the surface profile.

In general, it can be concluded that surface roughness increases with an increase in the feed rate and depth of cut and a decrease in cutting speed. Similar trend was also observed in the present work. Roughness is found to reduce drastically up to a particular critical value of surface speed [60] which is attributed to the reduction in size of the built up edge. At this speed, when the effect of the built up edge is considered negligible, the profile of the cutting edge of the tool (pointed or curved) gets imprinted on the work surface, and the surface roughness from this point on depends on the feed rate. A larger depth of cut, or in other words a larger chip cross-sectional area adversely affects surface finish though it is usually not significant until it is large enough to cause chatter. Note that the effect of increased feed is more pronounced on surface finish than the effect of an increased depth of cut. Thus, measures for improving machining productivity (increasing feed and depth of cut) work against achieving better surface quality.

2.5 Boring bar vibrations and surface roughness:

The focus of numerous and extensive studies that evaluate surface finish is usually centered on the effect that machining parameters (speed, feed, depth of cut, etc.) have on the surface quality. However, vibrations within the system can have an even more significant adverse effect on the surface finish of a machined component. These vibrations originate directly from the stiffness and damping capacity of the environment-machine-tool work-piece-clamping system. Most of the modern CNC machine tools manufactured recently have excellent stiffness and damping capacities when installed and calibrated appropriately. However no real machine can have infinite stiffness and thus
there is always a certain amount of vibration within any machine tool which cannot be eliminated.

Attempts have been made to use vibration signals in predicting tool wear and tool life in turning operations and other machining operations. In further literature discussion regards to use of vibrational data for predicting the tool wear, surface roughness, tool life, cutting forces, dimensional deviation and many more dependent variables have been varied out. Boring process however is not being focused till time for such type of analysis. A decades back M.S. Selvam [61] has made an attempt to find the effect of tool vibrations on surface finish. The frequency content of tool vibration and the surface profile in turning under normal cutting conditions was studied by measuring the frequency spectra of tool vibration and the surface profile. The cutting speed, work-piece rigidity and the method of fixing the work-piece were found to influence the surface roughness and tool vibration.


Beauchamp and others [65] have collected the surface roughness and tool vibrations data for mild steel for various set of speed, feed, depth of cut, tool nose radius, tool overhang and job length turn during turning. Here an algorithm for correlation between surface roughness and cutting vibrations for turning process is developed by Jang et al. [66] in concern to flexible manufacturing system. The effect of tool wear on the surface finish through vibrations in turning is studied by Mer and Diniz [67] under the effect of variable cutting parameters. Risbood, Dixit, Sahasrabudhe [68] predicted of surface roughness and dimensional deviation by measuring cutting forces and vibrations in turning process. Ghani, A.K., I.A. Choudhury, Husni [69] evaluated the tool life, vibrations and surface roughness produced by ceramic tools in nodular cast iron. H. Wang and others [70] presented a theoretical and experimental investigation of the
influence of tool-tip vibration on surface generation in single point diamond turning (SPDT).

Vibrational process during high-frequency vibration cutting is accomplished by treating cutting tool as an elastic structure which is characterized by several modes of natural vibrations. An approach for surface quality improvement was proposed by V. Ostasevicius et.al. [71] by taking into account that quality of machined surface is related to the intensity of tool–tip (cutting edge) vibrations. In the work presented they have considered an approach enabling to reduce surface roughness of the machined work-piece by means of excitation of the second flexural mode of the vibration of turning tool in the direction of vertical cutting force component.

2.6 On-line Monitoring and Control systems in Machining:

In a 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 interaction between system, process, product, the above goals have only partially been achieved today, to a limited, unsatisfactory extent. Despite lot of a research and technology development, control of the process is limited, both in terms of knowledge based parameter choice and at an automated level. This is particularly apparent when facing the extremes in terms of speed, materials or product geometry. Such limitation or risk often leads to conservative (safe) choice of parameters or of product development in order to avoid machine, tool or product failure. In contrast improved process understanding and the development of reliable, advanced process monitoring (or even control) could not only improve the productivity but also accelerate product development.

A process monitoring system was developed by Kaplan, Wangler and D. Schuocker [72] for laser cutting. The photodiode signal has lead to a high signal value when burning defects appeared at the cut surface, while the signal value was low for good cut quality. Defining a threshold value, good correlation between the signal detection alert and the temporary occurrence of burning damage at the cut surface was achieved. The detection of burning damage has led to a control strategy for reducing the cutting speed when burning damage appears in order to avoid it. This closed loop control was
successfully tested in an industrial environment leading to a minimization of burning damage but still to the highest possible cutting speed, thus keeping the optimum balance between productivity and quality.

The ability to monitor machining processes has rapidly increased during the past years, mainly depending on the fact that powerful low cost computers are available nowadays and that faster sensors and data acquisition cards (DAQ) have been developed. Also the global competition has forced the manufacturing companies to automate their machines to become less dependent on personnel. To achieve a higher degree of automation some kind of monitoring devices are needed. Shang-Lieng and Jen [73] developed a Data fusion neural network for tool condition monitoring in CNC milling machining. The trends are also directed towards systems integrated with the machine controller to be able to change the process during machining.

Kang et al. [74] placed a load cell near the ball screw providing a system that is cheaper than a tool dynamometer and that is also shielded from cutting fluids, even the wiring. It measures cutting forces but leads to errors of about 5% compared to the dynamometer. Kim et al. [75] measured the spindle displacement during milling with a capacitive sensor and succeeded in estimating the cutting force. It is also possible to measure the chatter of a process with a force sensor and to continue from this data to make decisions on how the process is developing. Many different sensors can be used for monitoring the status of the machine and environment and make it understandable for a machine controller. A summary of the sensor types, the use to which they are put and the level of research associated with each is presented by Dornfeld [76] as shown in Fig. 8.

Many researchers have tried to implement adaptive controller of machining processes. The first attempt was made in this direction by Centner and Idelsohn [77]. Another important industrial application of time frequency (TF) analysis is the monitoring of machinery vibrations to detect and diagnose defects, and provide early warning of impending machinery failure.
Les E. Atlas et al. [78] considered real-time monitoring of drilling vibrations for such analysis. They concluded that high-resolution TF analysis, designed specifically to work on non-stationary signals, is useful for extracting valuable information from manufacturing and machine monitoring sensor signals. Instantaneous monitoring of dynamic cutting force was used to predict the surface roughness by David M. and others [79]. They proposed discrete autoregressive moving average (ARMA) models and dynamic data system (DDS) analysis approach to analyze the cutting dynamics. Gil Abramovich and others [80] proposed a developmental approach for adaptive general purpose machine vision inspection. The architecture outlines an unsupervised sensory mapping followed by a supervised cognitive mapping for feature derivation and classification. The results are fed to the motor mapping, which in turn generates attention control to the sensory mapping and gives commands for further actions, such as part sorting. A cost-effective and reliable tool condition monitoring system (TCMS) was developed by C. Scheffer and P.S. Heyns [81] utilizing the advantages of NNs for a typical industrial machining operation. The operation considered is interrupted turning (facing and boring) of Aluminum alloy components for the automotive industry.
Real-time error compensation method is probably the most direct and cost-effective way to deal with external disturbances of unpredictable nature such as non-uniform depths of cut, spindle-motion errors, dynamic vibrations and so on. A small overhung boring bar servo system was developed by D. Gao et. al [82] for the real-time compensation of dimensional error of bored surfaces.

A piezoelectric controlled boring bar for active error compensation was developed by W.M. Chiu and K.W. Chan [83]. A computer-controlled piezoelectric actuator acts on the boring bar holder so that the tool displacements caused by instantaneous cutting force can be automatically corrected during cutting. PID control algorithms were written to simultaneously monitor the cutting force and to activate the piezoelectric actuator to position the boring bar so that the forced displacement of the boring bar can be corrected.

Various in-process techniques have been proposed and developed to measure the diameter of a work-piece in turning. Several techniques could be classified as contact measurements and others as non-contact measurements. These techniques are based on mechanical, optical, pneumatic, ultrasonic, electrical and temperature detection method. Most of these methods are non-contact measurements except the mechanical method, which uses a contact technique. The friction-roller type instrument and the caliper-type method are some examples of the mechanical methods applied to measure the diameter of a work-piece in in-process measurement. Recently, an electrical method has been developed for contact measurement by Liu [84] with improved repetitive measurement and compensation system to reduce work-piece.

Choudhury et al. [85] developed an on-line system to monitor tool wear and control work-piece dimensional deviations in turning. The tool wear was indirectly monitored by constantly monitoring the changes in the work-piece diameter. These changes were assumed to be the effects of tool flank wear. The system consisted of an optical fiber transducer, a stepper motor with a controller to activate the actuator and a predictive system based on a neural network.
A Sequential Forward Search (SFS) algorithm was employed by T.I. Liu and others [86] to select the best combination of machining features. Back-propagation neural networks (BPNs) and adaptive neuro-fuzzy inference systems (ANFIS) were used for on-line classification and measurement of tool wear.

Along with on-line monitoring, the control of machining processes was also considered by the different researchers. Our interest is basically to deal with the literature on controlling of tool vibrations in either of the machining process. Vibrations are greatly affected by the machining parameters. S.C. Lin et al. [87] used the control of machining parameter technique to control the tool vibrations in turning. The technique of using composite material boring bar for stabilization of relative motion between tool and work piece to suppress the vibrations was effective employed by S.K. Choudhury and others [88]. Vibration control has also been achieved with the help of an active dynamic absorber to improve the cutting process stability using boring bar by S.G. Tewani [89] and R.G. Klein [90]. Elimination of chatter in milling process by controlling the spindle speed was introduced by Smith and Tlusty [91].

A state feedback control system based on the observed estimates of the states to suppress machining chatter was employed by Shiraishi [92]. S.K. Choudhury et al. [93] developed a system for on-line vibration control in turning on lathe. A bifurcated bunch of optical fibres was used to sense the relative vibrations between work piece and cutting tool which was then phase shifted, magnified and fed back to the piezoelectric vibrator which supports the tool. Experimental investigation found a significant improvement in the dynamic characteristics of the machine tool resulting in considerably higher productivity, accuracy and surface finish.

Machine tool controls can be generally classified into three levels according to their scope of operations: servomechanism control loop, interpolation loop, and adaptive or simply process control loop. The objective of the servomechanism control loop is to regulate the position and velocity of machine slides and spindles in the face of adverse disturbances such as friction, stiction, backlash, machining forces, etc. The objective of the interpolator loop is to coordinate multiple axes to maintain a specified tool path and orientation. Process control, which is not commonly integrated into today’s machine tools, is the automatic adjustment of process parameters e.g., feeds, speeds, in order to
increase operation productivity and part quality. The servomechanism controllers regulate the velocity and position of individual axes and spindles and interpolators generate the reference positions of the axes.

After an extensive literature review carried out it was found that there is great scope to study the effect of boring bar vibrations and its effect on surface roughness. In the present work efforts were made to find the correlation between boring bar vibrations and surface finish. Industries are still looking for a simple, rigid and reliable way for on-line measurement of surface roughness.

Though on-line measurement of surface roughness is impossible, but on line measurement of cutting tool vibrations is possible. With this view, several cutting trials were carried out for under different cutting conditions. Results are summarized to find the variation of acceleration for different machining condition. The surface roughness was also measured off-line. A correlation was worked out between acceleration and surface roughness with various cutting parameters. Optimum values of cutting conditions were found out to maximize the material removal rate and hence minimize machining time.

A model is prepared for the above system in Simulink tool of MATLAB. It was then simulated to check the workability of the proposed technique. An PIC microprocessor based control system was also developed, tested and found to be working satisfactorily as per the technique discussed.