6.1 CONCLUSIONS OF THE GRINDING FORCE MEASUREMENT AND OPTIMIZATION

This thesis involves the development of simple instrumentation setup to measure the forces in cylindrical grinding which can be implemented with ease without any modification in the machining setup, unlike the systems which have been reported. Investigation has been carried out to study the effect of grinding parameter and its optimization with respect to the surface roughness, the variation of surface hardness, and the tangential and normal grinding forces in cylindrical traverse grinding. Development of experimental setup for measurement of forces and the optimization of grinding parameters are summarised and inferences are drawn.

6.1.1 Conclusion of the Grinding Force Measurement

1. In this study, a force measurement setup that can measure the tangential and normal grinding forces by using strain gauge has been developed. The detailed investigation was conducted in ANSYS to analyze and identify the region of strain in the stationery tailstock in the cylindrical grinding due to grinding forces. It is observed from the ANSYS results that the elastic deformation is more in the area of conical portion of the dead center and it increase with an increase in the load. From the
result the position of placing the strain gauge has been identified which will be subjected to considerable stress.

2. The force measurement circuits, the procedure for recording the grinding force signal, calibration of the experimental setup have been described. The tangential grinding force was measured and also derived from the measured grinding power, and both values have fairly agreed.

3. It is observed from the grinding force signal plot, the tangential and normal grinding force signals have same trend and the maximum amplitude of force signal has been found at the time of full contact between the wheel and the workpiece.

4. The grinding power plot reveals that the grinding power was constant during the period when the wheel is in full contact with the workpiece. The tangential force obtained from the grinding power is in good agreement with the force measured from the experimental setup.

5. An experimental investigation was carried out to study the effect of the cylindrical grinding parameters (Work speed $V_w$, Depth of cut $d$, traverse feed $f$) on the tangential grinding force, the normal grinding force, and the surface roughness of the ground piece in grinding En19 alloy steel using full factorial design($3^3$).

6. The results of the grinding show that the tangential grinding force increases with an increase in the depth of cut, traverse feed and the work speed. The increase in the depth of cut leads to the increase in the removed chip thickness, which in turn, increases the tangential grinding force. The increase in the traverse feed and the work speed increases the average
chip thickness and length, which results in a higher tangential force.

7. The results of the study show that the normal grinding force increases with an increase in the depth of cut, traverse feed and the work speed. The decrease in the depth of cut leads to increase more grains to remove a given volume of material, which in turn, reduces the normal grinding force. The higher the values of the traverse feed and the work speed result in increasing the chip thickness and the contact area, which in turn increases the normal grinding force.

8. The grinding results show that the values of the surface roughness increase with an increase in the depth of cut, the traverse feed and the work speed. The increase in the value of depth cut causes grain fracture or to pull out there by increasing the grain space and reduces the number of grains per unit area, which in turn, produce poor surface roughness.

9. The poor surface finish ($R_a$ 2.53µm) was obtained at the work speed of 0.6m/s, depth of cut of 0.03mm and the traverse feed of 0.3 m/min. The grinding parameters at maximum work speed, high depth of cut and maximum traverse feed resulted in a poor surface finish.

10. The fine surface finish ($R_a$ 1.17µm) was obtained at the work speed of 0.36m/s, depth of cut of 0.01mm and the traverse feed of 0.1 m/min. The grinding parameters at minimum work speed, low depth of cut and minimum traverse feed resulted in a fine surface finish.
6.1.2 Conclusion of the Optimization of the Grinding Parameters

1. Taguchi technique has been applied to optimize the parameters of the cylindrical grinding.

2. ANOVA results show that the depth of cut, the traverse feed and the work speed have significant effect on the considered quality characteristics (surface roughness, variation of surface hardness and the tangential and normal grinding forces), among the four controllable factors (work speed, depth of cut, traverse feed and coolant flow rate). The coolant flow rate influences the surface roughness only and it is insignificant to the surface hardness, the tangential and normal grinding forces.

3. The optimization results show that, the depth of cut is found to be the prominent influencing parameter on the surface roughness, the surface hardness, the tangential and normal grinding forces followed by the traverse feed and the work speed.

4. The coolant flow rate is observed to be an insignificant factor except for the surface roughness. Although, the coolant flow rate influencing the surface hardness, its effect on surface hardness is insignificant.

5. Confirmation experiments were conducted to verify the values of quality characteristics using the optimal combination obtained from the Taguchi technique. The predicted values are in good agreement with the experimental value.
6.2 SCOPE FOR FURTHER RESEARCH

The grinding force measurement in cylindrical grinding can be extended to workpiece of any dimension in a conventional cylindrical grinding process and without any modification in the machining setup. The setup can be extended for in-process monitoring of grinding force by interfacing the setup and programmed exclusively using suitable software. In-process force monitoring can be used to monitor the homogeneity of the composite material during grinding. Incorporation of the wheel speed and the dressing lead as grinding parameters, helps to understand the trend of quality characteristics more deeply. Also, the work can be extended for the significant analysis of the surface roughness and the surface hardness by increasing the number of replications.