On-Line Optimisation And Experimental Design Analysis For The Investigations On The Surface Roughness Produced By Roller Burnishing

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To

Komaraiah Koorapati

with greatest gratitude

ABSTRACT

This thesis describes the improvement of the Surface finish of metals by a cold working, non-metal removal and plastic deformation process called roller burnishing. Roller burnishing is a popular finishing process. Surface finish has a positive and prolonged effect on the functioning of the machined parts. In this work roller burnishing is used to get a high quality surface finish on different materials like aluminum, copper, mild steel and brass. A roller burnishing tool was designed and fabricated for the project.

A test rig was set up on a center lathe to conduct experiments. The angle of approach and radius of the roller burnishing tool were checked for optimisation. Number of passes of the tool was also one of the factors under study for the optimisation. The surface finish of the roller burnished cylindrical surfaces was examined for the soft materials like Aluminum and Copper and also for the hard materials like Mild Steel and Copper. The optimum values of feed, speed and depth of penetration were suggested by conducting a number of experiments varying one factor-at-a-time holding the rest constant.

Since all the factors are interdependent, varying one-factor-at-a-time and keeping the rest constant method of experimental optimisation technique will not give accurate results either for the main effects or any interactions present. At same time it is not possible to vary more than one factor at a time experimentally.

Hence a theoretical approach focused on the computer based, process parameters and surface quality data acquisition from the shop floor was suggested. The collected data was then analysed by Design of Experiments method, an advanced statistical quality analysis method, to determine the significant process parameters influencing the surface finish. The basic design and analysis of the process was carried out by full factorial and ANOVA for the two level three factor (2^3) experimental design.

More experiments for roller burnishing process were conducted for collection of data using experiments designed by the Central Composite Design (CCD) method. These experiments were used to determine the interactions among the factors. The analysis was carried out by the Response Surface Methodology (RSM) to find the optimum values of the more significant process parameters. The final surface finish for mildsteel was found to be 0.32μm with a feed

of 85μm/rev and depth of penetration of 70μm. The results of both experimental and theory were compared.

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Chapter 1

Introduction

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1.1 Surface finish obtainable in various processes

With the advent of New Technology and increased demand, the necessity for accurate and quality components has increased. The quality of the components and the assembly can be improved considerably if they are finished better.

The functional performance of a machine component such as load bearing capacity, fatigue strength, resistance to wear, resistance to corrosion depend to a large extent on surface finish of components. Some of the factors that influence the surface characteristics are geometrical features of the surface, hardness and the residual stresses induced.

These machining processes can be divided into three groups.

1. Primary machining processes
2. Finishing processes
3. Fine finishing processes

The primary machining processes include turning, milling, drilling, boring, disc grinding and hand grinding etc. The surface finish in this process varies from 0.32 to 25 microns (μm). The actual value obtained depends up on the machining parameters such as the cutting speed, feed, and depth of cut, application of coolant, rigidity of work-tool-fixture and machine tool system. In the case of disc and hand grinding operations the grain size plays an important part.

In these finishing processes surface grinding, cylindrical grinding and reaming are included. The roughness obtainable in these processes varies between 0.06 to 5μm.The grinding operation, though superior to reaming with regard to roughness, the residual stresses existing on the ground surface are reported to be tensile in nature. The tensile residual stresses will reduce the fatigue life of the components. The situation is better in this regard with reaming.

The fine finishing process are grouped into two categories, one involving with removal of asperities through micro chipping and the other by causing gross plastic flow of the material at the surface. In the honing, lapping, polishing and super finishing operations very fine abrasives are used for improving the surface finish. The abrasives used may be in the form paste or a stick. The finish obtainable in this category of processes is between 0.01 to 0.4μm. In the second category of fine finish processes, there is no removal of material but only plastic flow of asperities at the work piece surface. This is caused by the use of a burnishing tool or by pushing a ball through the hole. The surface roughness obtainable in burnishing is between 0.04 to 0.8μm. The major advantage of these processes is the existence of a residual compressive stress field on the finished surface of the work-piece. Considerable strain hardening of work-piece surface also takes place resulting in better wear resistance and fatigue life. The sizing of the component is also found to be better.

1.2 Burnishing Process

It is basically a cold working processes in which the Machined surface undergoes a plastic deformation by the application of the pressure through a hard roller. As the surface pressure increases the metal from the crests (peaks) displace plastically to fill the troughs (valleys) of the surface irregularities. This results in reduction in height of the micro irregularities of the surface roughness. Burnishing causes work hardening and creation of beneficial compressive stresses in the surface layers [Azarevich G. M (1972)]. During burnishing operation, there will be a continuous plastic deformation of the work material and accordingly the surface finish changes.

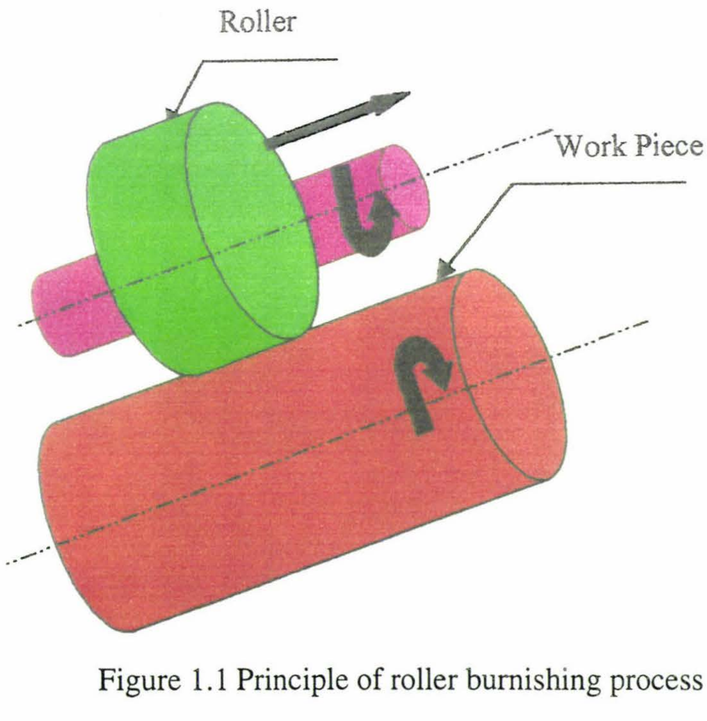


Figure 1.1 Principle of roller burnishing process

Due to the unevenness of the initial surface and high specific pressure, the smoothing out process is extremely intensive in the beginning even with comparatively low burnishing forces but later on it becomes less intensive due to work hardening effect [Adel M.H and Al-Basharat A. S (1996)] in surface layers.

More than ninety five percent of total machining work is done by metal cutting processes like turning, milling, drilling etc. These initial machining operations give the required shape and size to the components and to improve the surface characteristics of the components, the components are subjected to a metal finishing process. The finishing process, apart from improving the functional performance of the component, also improves the life of the component and gives a better appearance.

The dimensional accuracy, form deviations and surface smoothness can be achieved by properly selecting the finishing process. Table 1.1 indicates the surface roughness expected from various manufacturing processes.

It is understood that when compared to other finishing processes, the burnishing process offer certain specific advantages like work hardening of the surface layers, higher wear resistance, higher fatigue strength, precision sizing [Koti V. C and Ronanki L. M (1990)] of the component etc. Burnishing is an important member in the family of surface finishing processes.

1.3 Classification of burnishing process

The burnishing process is classified as the following and it is classified based on the process and shape of the tool.

1.3.1 Shape of the deforming tool

The burnishing tools are designed to have the deforming element either in the form of a ball or a roller. Thus the process is named as ball burnishing or roller burnishing as per the shape of the deforming element. The comparative features of various finishing processes are in Table1.1.

Primary Machining Processes:

S.No	Manufacturing Process	Surface finish in Microns
2	Drilling	1.6 --- 20.0
3	Boring	0.4 ----6.3
1	Turning and Milling	0.32 –25.0
4	Disc Grinding	1.6 ----25.0
5	Hand Grinding	6.3 ----25.0

Finishing Processes:

1	Cylindrical grinding	0.63 -----5.0
2	Reaming	0.4 -------3.2

Micro chip removal processes:

1	Honing	0.025 --0.4
2	Lapping	0.012 --0.16
3	Polishing	0.04 -- 0.16
4	Super finishing	0.016 --0.32

Chipless process:

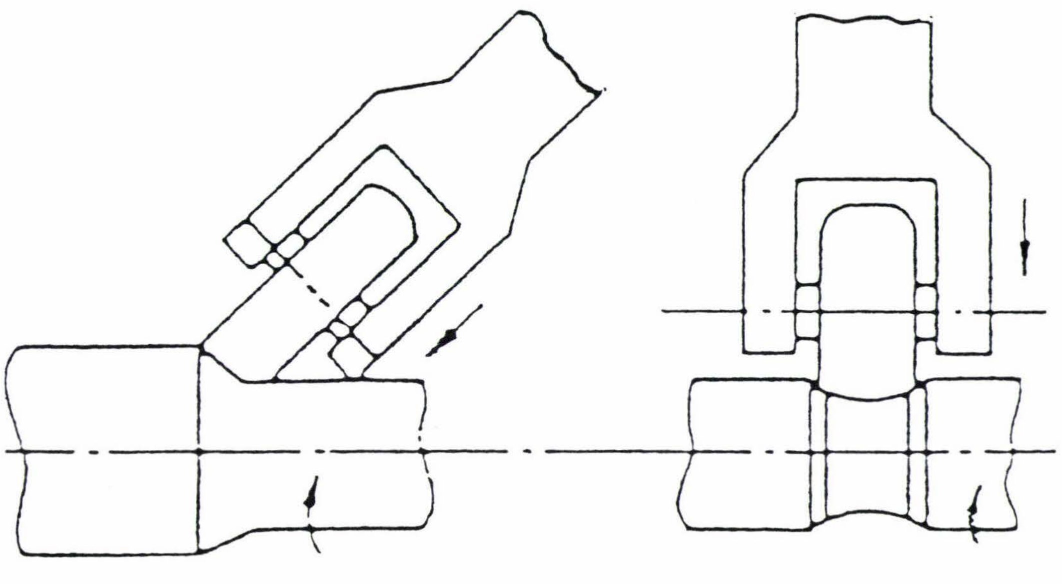
1	Burnishing	0.04 --0.8

Table 1.1 Surface finish obtainable in various manufacturing processes

1.3.2 Number of deforming elements

To get more productivity, multi ball or multi roller burnishing tool with two or more balls or rollers working on the surface of the job is employed. The number of deforming elements depends on the diameter of the work piece apart from the type of production.

Surfaces that can be burnished include external and internal cylindrical and tapered surfaces, spherical surfaces and flat surfaces. Gear tooth forms can also be burnished by using finger type burnishing tool [Loh N.H and Tam S.C (1989)].



a. External burnishing

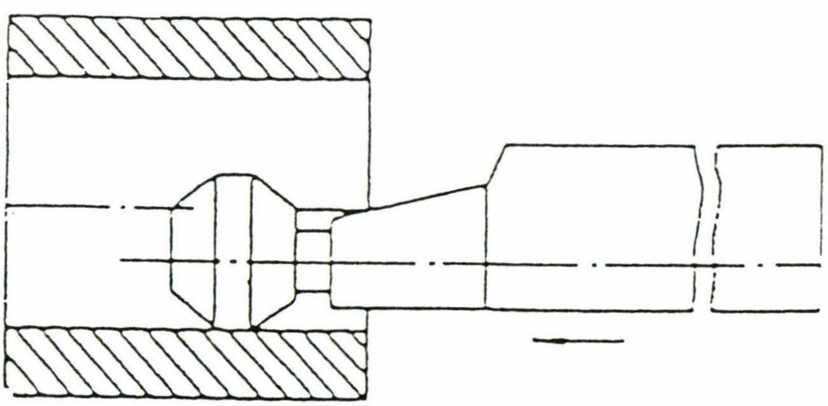


Figure 1.2 Types of burnishing

1.3.3 Motion of the tool

Depending on the relative motion of the tool at the contact zone on the surface there are three types of burnishing processes. In 'impact Burnishing', hardened rollers rotating around bearing on cams rise and fall rapidly delivering as many as 20,000 blows per minute. The metal surfaces are treated and finished by combined action of rolling and peening

1.4 Work requirements

All the ductile materials can be easily burnished. The quality of surface finish in burnishing depends on the hardness of the work piece and its ductility. For best results and maximum tool life the work piece hardness should not exceed 40 R_C. Materials with a tensile strength up to 1400 N/mm^2 and ductility of at least 5-8% may be burnished [Lee S. G and Loh N.H (1996)].

Surface finish of the work piece prior to burnishing plays a dominant role in determining the final surface finish. Ductile materials like brass, aluminum and annealed steels can have rough machined surfaces prior to burnishing. Materials like cast iron, steels above 35 R_C should have smoother machined surfaces and lesser stock allowance (i.e. the amount of material to be removed) [Lee S. G, Tam S.C and Loh N. H (1993)]. The ideal surface for burnishing is uniform peak and valleys pattern generated by a single point tool. By burnishing, the material flows from peaks to valleys and a fine surface finish is obtained.

While burnishing hollow work pieces, the wall thickness of the work piece should be strong enough to withstand the pressure of the burnishing tool. While burnishing thin walled work pieces there should be supporting fixtures to hold the job.

Parts with keyways and other interruptions or cutouts, which do not exceed 10% of circumference, can be burnished to obtain a good surface finish. Large cut outs tend to relieve the burnishing pressure of the tool. As a result, areas opposite to them may have a slightly rough surface finish.

1.5 Advantages of burnishing process

In the burnishing process the pressure of the roller causes, projections of the micro irregularities of the surface are to be plastically deformed, the roughness of the surface is reduced, its hardness is increased and residual compressive stresses in the surface layer rise, preventing the growth of cracks.

- Net improvements in the surface finish. In a burnished surface, there are no cracks, pits, burns, voids and gaps
- Improvement in the surface hardness to a considerable depth
- Improvement in dimensional accuracy. The geometrical tolerances like straightness and cylindricality can be maintained by reducing the out of roundness
- Increase in fatigue strength
- Induction of residual compressive stresses
- Improvement in wear resistance, friction resistance and anti corrosiveness
- short machining times and hence high productivity
- No need of coolants as the temperature involved in the burnishing process is low
- Longer tool life
- improvement in the percentage ratio of contact area

1.6 Applications of burnishing process

Burnishing can be used for:

- Finishing bores of hydraulic and automobile cylinders. Honing can be replaced by burnishing
- Finishing outer surfaces of pistons of hydraulic machinery

- Increasing contact area of valve seating in Internal Combustion (I.C) Engines
- Increasing the wear resistance &fatigue strength of rail axles
- Improving the quality and reducing the friction of main journals and crank pins of crank shafts and cam shaft journals of motor vehicles.
- Hardening the surfaces of tooth flanks of gears and plastic components

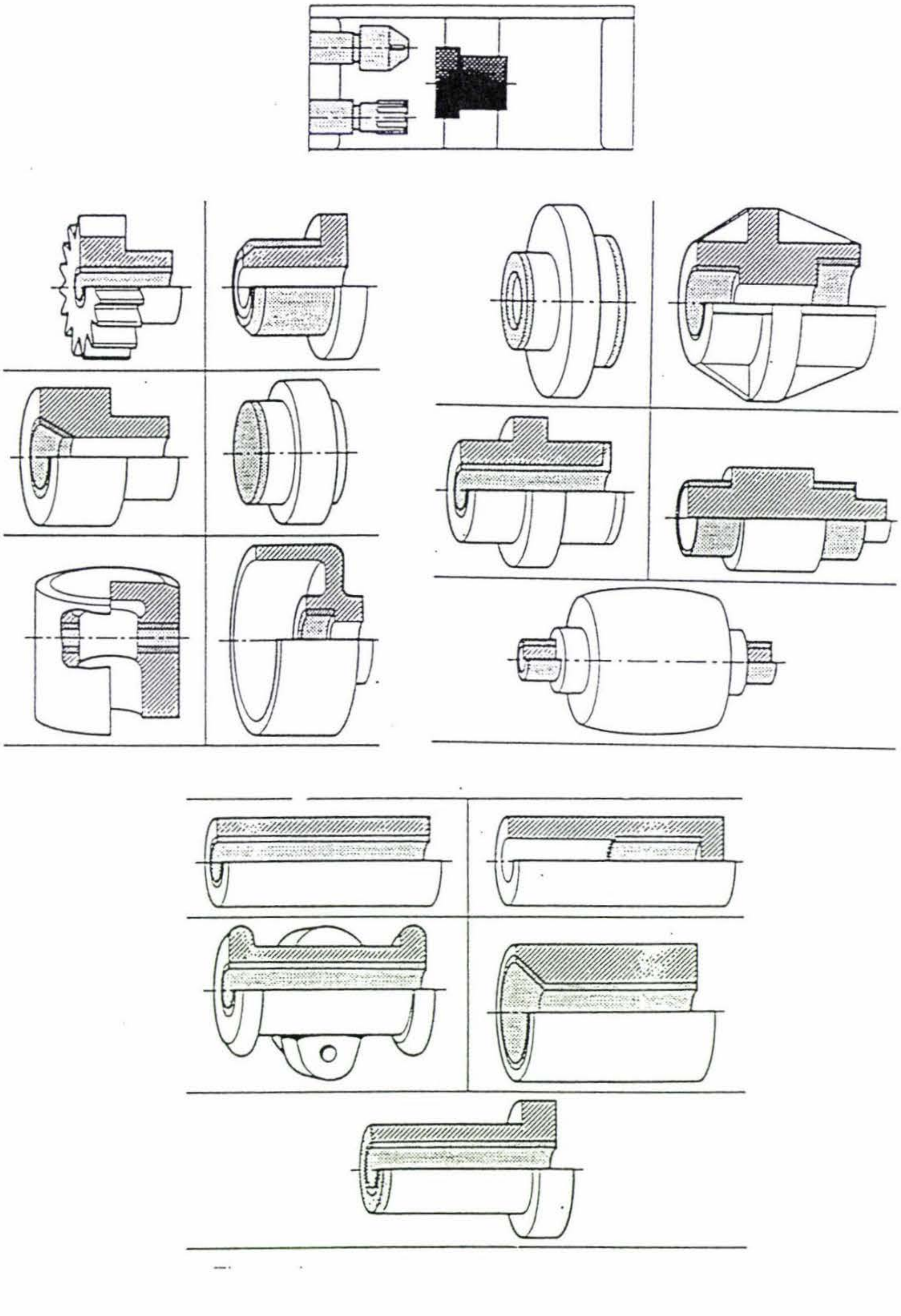


Figure 1.3 Applications of burnishing process

More applications are in the appendix-1.

1.6.1 Surface roughness and dimensional tolerances

Surface roughness is closely tied to the tolerance of a machine component (Table 1.1). A close tolerance dimension requires a very fine finish, and the finishing of a component to a very low roughness value may require multiple machining operations. For example a 3.2μm surface roughness can be produced by milling or turning, while a very fine (low roughness value) surface would require grinding or additional subsequent operations, such as honing, super finishing, abrasive flow or burnishing. Therefore specifying very fine finishes will normally result in increased costs.

The importance of surface integrity is further heightened when high stresses occur in presence of extreme environments. Heat resistant, corrosion resistant and high strength alloys are used in a wide variety of such applications. Typical alloys used in these applications include alloy steels with hardness of 50 to over 60 HRC and heat treated alloys with strength levels as high as 2070 MPa. Additional materials include stainless steels titanium alloys, and high temperature Nickel-based alloys developed for high temperature and corrosion-resistant applications [Gambin W (1996)].

Unfortunately the alloys suitable for high strength applications are frequently difficult to machine. The hard steels and high temperature alloys, for example, must be turned and milled at low speeds, which tend to produce a built up edge and poor surface finish. The machining of these alloys tends to produce undesirable metallurgical surface alterations, which have been found to reduce fatigue strength.

The typical problems in surface finish include:

- Grinding burns in high straight steel air craft landing gear components
- Grinding cracks in the root sections of cast nickel base gas turbine buckets
- Lowering of fatigue strength of parts processed by Electric Discharge Machine
- Distortion of thin components
- Residual stress induced

1.6.2 Surface alterations

The types of surface alterations associated with metal finishing operations are:

Mechanical: Hardness alterations, plastic deformations, cracks (microscopic and macroscopic), and residual stress distribution in surface layer

Metallurgical: Transformation of phases, grain size and distribution, precipitate and distribution, twinning, recrystallisation and resolutioning or austenite reversion

Chemical: Intergranular attack, intergranular corrosion, intergranular oxidation, contamination, embrittlement by the chemical absorption of elements such as hydrogen and chlorine, pits or selective etch and corrosion

Thermal: Heat effected zone, recast or re-deposited material, re-solidified material and splattered particles or re-melted metal deposited on surface

Electrical: Conductivity change, magnetic change and over heating

1.6.3 Sizing consideration may overweigh finish

Sizing and surface improvement are usually considered separately in applications of roller burnishing. The rolling action does change size and this effect is exploited in several ways.

- To control quality of press fits

Suppose a part made on a turret lathe or automatic is to be reamed to size for a press fit preferably with a reamer ground to produce a proper peak to valley pattern. In the course of time the tolerance will drift as the tool wears. Obviously, at assembly the tighter part will give a different degree of press fit, and this change may prove to be undesirable [Bokov M and Markas L. I (1972)].

The burnishing action compacts the metal, produces a greater degree of contact with the mating part and achieves the desired uniformity in hole size, net result is a gain in the quality of the press fit.

- Sizing of sleeve bearings for proper fit with shafts

End bells for a certain_electric motor require that a bronze bushing 1 in. long be pressed into support a ¾ in. shaft. During the pressing operation the bushing closes in 0.001 in. instead of reaming or broaching, the bore is roller burnished at a rate of 300 pc per hour on a drill press. The bushing inner diameter (ID) is rolled to 0.0005in. above nominal size and the sizing operation locks the part in the bore.

1.6.4 Metallic Seals

Metallic Seals are of three general types reciprocating, rotating and stationary production of high quality finishes on sealing surfaces usually under (10micro inch.) is essential if seals are to control leakage of air, oil, grease or water.

The customary method of producing this class of finish on a sealing surface is to use grinding, often followed by honing. These operations require more time and expense than roller burnishing. There is always a chance that embedded abrasive will be present to wear out the mating sealing element.

- Sealing surfaces

Sealing surfaces in or on production parts can be of many kinds: face seals, angular or taper seals or seats, ID or outer diameter (OD) seals, recessed seals, under cut seals and combinations of these general types.

- Sealing Elements

The sealing element that contacts the sealing surface may be soft (O-ring leather or plastic) or hard (graphite, graphite impregnated bronze, Stellite, steel or ceramic). Usually these are purchased parts for the assembly and are often renewable. The sealing surface in the product is the one that will be machined, and very often it can't be salvaged if incorrectly made or worn beyond service limits.

- Poor Seals increase costs

An automobile manufacturer found that many transmissions leaked while the vehicles were still under warranty. Cause: worn out O-rings. After a switch to roller burnishing the bores, large sums were saved.

- Valve Seats

The valve industry ranks first as a producer of seats. Most of these seats are tapered, some are flat, and they are used in valves for water, oils, gas, and air. Metal-to-metal seats are likewise used in pipefittings. In any case excellent geometry and finish are required for a seat to prevent leakage [Konalov E.G (1970)]. The finish should range from 8 to 12 micro- inches.

- Checking plug bodies

In checking plug bodies, they are blued to 80% contact, and the tolerances on the seat must be held to 0.00075in. for the entire length of the taper. Taper length can be two to three times the diameter.

This relationship magnifies roller burnishing problems (as compared to valve seats as a whole). Metal displacement becomes more difficult, the tapered surface is hard to generate, and the taper reaming as the prior machining step does not produce a suitable surface.

In burnishing a taper, the wall thickness surrounding the burnished surface should be uniform to avoid creating an egg shape.

- Burnishing Hydraulic cylinders

In many applications hydraulic cylinders are fitted with O-rings and a good finish is therefore required. The maximum allowable roughness is 15 micro inches. Sometimes the cylinders are fitted with glands and the seal faces are found only in those glands. In other instances the finish on the rod is very important (as in lift cylinders for form equipment and construction machinery)

- Long cylinders

In long cylinders waviness can't be corrected by honing, but such a condition is probably not important any way. There are two ways to hone (1) to size (2) to finish. In the first instance a lot of stock is removed by honing. A cheaper way to do this work is to pack bore to size, then burnish. The pack-boring tool is faster and can be made to produce the desired peak to valley distance for a good burnishing job.

In heavy-wall tubing is required, it can be produced by forging or trepanning, but the next problem is to find a shop with equipment capable of honing the part.

- Telescoping cylinders

In various hydraulic lifts the designer uses telescoping cylinders. Here the OD finish is also important. Much of this work has been done by turning to size and then finishing by cylindrical or belt-grinding [Pavlov V.A (1975)]. The newer technique is to turn and then immediately burnish in the same machine using a hollow burnishing tool that follows behind the turning tool. Any length of tubing can be processed.

- Small cylinders

Commercial air and hydraulic cylinders require two finishing operations: (1) Burnish the ID to 5-10 micro inches, and (2) Burnish the end piece or end cap to a good finish.

It is cheaper to ream and burnish an end cap in an automatic than it is to hone on a separate machine.

In respect to the cylinder's ID the cost of burnishing will probably be less than the cost of honing stones. The burnishing rolls have a long life.

1.7 Scope of the present work

The present work aims at studying the influence of roller burnishing process on the response factor surface finish. Experiments on the roller burnishing process were conducted under varying conditions of process parameters on different work materials like Aluminum, Brass, Copper and Mild Steel. These experiments were conducted to study the influence of main and interaction effects and also to get the optimum values of various process parameters such as burnishing force, feed, speed and depth of penetration for the best results of response factor i.e. surface finish. Other factors such as number of passes and tool approach angle were also under study for the experimental optimisation for the best results of the response factor.

The experimental optimisation was carried out for the burnishing process parameters feed, speed and depth of penetration by one-factor-at-a-time technique. The geometry of the tool was also optimised experimentally for its tool approach angle and radius. The number of passes had also got significant effect on the surface finish. The work materials selected for the experimentation were mild steel, copper, brass and alluminum. The experimental technique of changing one-factor-at-a-time optimisation might not give satisfactory results, because all the factors were inter-dependent. It was not possible to calculate interaction effects among them. Hence the experimental results were analysed theoretically for the optimum values of the process parameters by the 'Statistical Design Analysis' technique.

For the purpose of this project one of the materials most commonly used one, mild steel was selected, to determine the optimum input parameters for minimising the surface roughness the method used was 'Design of Experiments'. The 'Full factorial two level three factors Design' (2^3) was chosen as an initial screening method to select key input parameters which have significant effects on the 'Surface Roughness'. But it was observed that there was a curvature present. Computer print out with all details also enclosed in appendix-2. Then the design was changed to 'Central Composite Design' (CCD) with 3 factors full factorial design. For analysis of the main and interaction effects of the most significant factors 'Response Surface Methodology' (RSM) was used. Then the significant factors optimum values were found by using regression by drawing Response Surface (RS) plots.