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Optimization of Surface Roughness Index for a Roller Burnishing Process Using Graph Theory and Matrix Method

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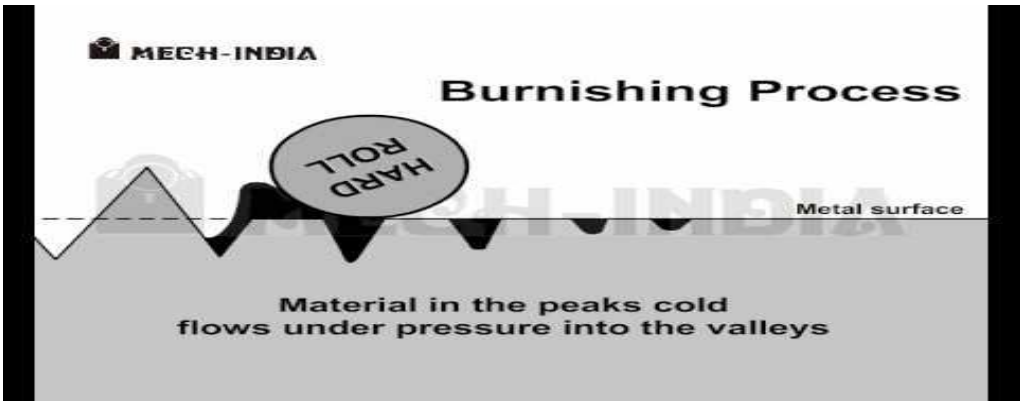
Abstract: **The main objective of this dissertation is to optimize the roughness index for a roller burnishing process. The factors have been identified from literature review. These barriers may be of market, cultural, human resource .management, financial, economical, attitudinal, environmental, geographical and technological type. Technology transfer barriers threats the movement of physical structure, knowledge, skills, organization value and capital from the developed to developing countries. Clear understanding of these barriers may help the practitioners to find out various ways to deal with them. This may further facilitate successful implementation of technology transfer. Technology transfer may be said to be successful if Transferor (seller) and the transferee (buyer) can effectively utilize the technology for business gain. The transfer involves cost and expenditure that should be agreed by the transferee and transferor. The process is affected by various factors that hinder Technology Transfer. These factors named Barriers. In the present work, Interpretive Structure Modeling(ISM) is used for the analysis and comparison of various factors important for Technology Transfer. The important parameters are identified and self-interaction matrixes proposed with the help of Interpretive Structure Modeling which evaluates the inhibiting power of these parameters. This index can be used in comparison of different factors responsible for Roller Burnishing Processes.**

Keywords: **Roller Burnishing Processes, important parameters, Interpretive Structure Modeling(ISM).**

1. INTRODUCTION

Roller burnishing process:

Roller Burnishing (RB) is one of the no-chip finishing processes for surface engineering. Roller Burnishing is a cold working, surface treatment process in which plastic deformation of surface irregularities occurs by exerting pressure through a very hard and smooth roller on a surface to generate a uniform and work-hardened surface. The burnishing process is an attractive finishing technique which can increase the work piece surface strength as well as decreasing its surface roughness.



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Advantages of Roller burnishing process:

- Improved Metallurgical properties- work hardened surface, Increase in fatigue strength.
- No Additional Machine Investment- attachable to any Standard Machine tool already present in the shop.
- Long tool life, no operator skill required, low torque & power requirements, maximum part interchangeability.

Characteristic Features of the Burnishing Process:

External burnishing can employ either ball or roller but an internal surface requires roller burnishing. Roller burnishing tools consist of a series of tapered highly polished and hardened rolls positioned in slots within a retaining cage. The tool is adjustable within work piece to develop a pressure that exceeds the yield point of the work material. Practically any metal with hardness up to Rc 40 can be easily burnished. Harder materials require still harder roller material viz carbide [2], ceramic [3] or diamond [4, 5, 6] though ductility and malleability renders the material easy to burnish. Brittle materials like CI have also been burnished [7] because they can withstand compressive force though the mechanism may be different in the burnishing of such materials. The effectiveness also is low. Burnishing allowance depends generally on the size and ductility of work so does 'the final result. A low carbon steel or 40 to 50 mm diameter can be given a burnishing allowance of 0.01 to 0.02mm and can be expected to produce a finish of 0.1 to 0.2 µm Ra [8, 9].

2. GRAPH THEORETIC APPROACH

GTA is a systematic and logical approach that is applied in various disciplines [10, 11, 12].The conventional representations like block diagrams, cause and effect diagrams and flowcharts do not depict interactions among factors and are not suitable for further analysis and cannot be processed or expressed in mathematical form. The following features highlight the uniqueness of this approach over the other similar approaches:

- It is a single numerical index for all the parameters.
- It is a systematic methodology for conversion of qualitative factors to quantitative values, and mathematic modelling gives an edge to the proposed technique over conventional methods.
- It permits presents modelling of interdependence of parameters under consideration.
- It allows visual analysis and computer processing.
- It leads to self-analysis and comparison of different organisations.

Main Elements of GTA:

1. The digraph representation
2. The matrix representation
3. The permanent function representation.

The graph theoretical methodology consists of three steps – digraph representation, matrix representation and permanent function representation. A digraph is used to represent the structure of the system in terms of nodes and edges wherein the nodes represent the measure of characteristics and the edges correspond to dependence of characteristics. Matrix representation is one to one representation of the digraph. Permanent representation is the mathematical expression of characteristics and their interdependence. Digraph representation, matrix representation and permanent function are developed for the quality, cost, reliability and efficiency characteristics. The elements of the diagram are the syntax symbols and the diagram itself is considered to be a sentence which describes the system. A graph is defined by an ordered pair G= S, c where "S" is the vertex set and "c" the edge set and every edge is defined by its two end vertices. If each edge in the graph has a direction, the graph is known as a directed graph or the Digraph. If the digraph is a network graph, each edge and the vertex have properties of flow and the potential in the system respectively.

An engineering system is usually represented as a diagram, with nodes, lines, and words or numbers which assign values to some or all nodes or lines. For instance, it is common to use a diagram to show a truss, or a mechanism, or a gear system, or electrical circuit, or a mass-spring dashpot oscillator. The elements of the diagram are syntax symbols, and the diagram itself is considered to be a sentence which describes the system. Following mathematical tradition, the work should be done in two parts.

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1. Check whether the problem is well defined and hence solvable. In the words of logic, check that the syntax of the engineering system being dealt with, in other words, its diagrammatic representation, is a Well-Formed Formula (WFF). This question is usually dealt with in a cursory fashion in engineering work. Attention is immediately focused on the numerical mathematical formula to be applied to a problem, with no systematic attention paid to whether the system is correctly defined. For instance, as will be shown later, the rule often used to determine if a truss structure is just-stiff, is not a complete solution to that question. However, when viewing the truss as a graph, this question has a proven algorithmic solution.

2. Before proceeding into the analysis effort, ensure that the solution will require as low a computational effort as possible. This is of less practical importance for small systems, but is very important for large systems with many components. This subject is usually dealt with by heuristic rules of thumb, known as expert domain knowledge. When using the graph theory representation of the engineering system, it can often be dealt with using mathematically proven algorithms of graph theory rather than man- made heuristic rules.

3. MATRIX REPRESENTATION

Digraph presentation is very suitable for visual analysis but is not very suitable for computer processing. Moreover if the system is large, its corresponding graph is complex and this complicates its understanding visually. In view of this, it is necessary to develop a representation of the CCPP that can be understood, stored, retrieved and processed by the computer in an efficient manner. Many matrix representations for example adjacency and incidence matrix available in literature. The adjacency matrix is a square matrix and is selected for this purpose. It being a matrix and multinomial has been derived subsequently based on connectivity only, neglecting the directional properties. Matrix for n=6 are shown below:

$$H=\begin{matrix} B1 & 0 & b13 & 0 & 0 & 0 \\ b21 & B2 & b23 & b24 & b25 & b26 \\ 0 & 0 & B3 & b34 & b35 & b36 \\ 0 & 0 & 0 & B4 & 0 & b46 \\ 0 & 0 & 0 & b54 & B5 & b56 \\ 0 & 0 & b63 & 0 & 0 & B6 \end{matrix}$$

In an undirected graph, no direction is assigned to the edges in the graph. Where as directed graphs or digraphs have directional edges. An undirected graph has a symmetric adjacency matrix and therefore has real eigenvalues (the multi set of which is called the graph's spectrum) and a complete set of orthonormal eigenvectors. While the adjacency matrix depends on the vertex labeling, its spectrum is a graph invariant. Undirected graphs often uses the former convention of counting loops twice, where as directed graph typically uses the latter convention. There exists a unique adjacency matrix for each isomorphism class of graphs (up to permuting rows and columns), and it is not the adjacency matrix of any other isomorphism class of graphs. If the graph is undirected, the adjacency matrix is symmetric. The main diagonal of every adjacency matrix corresponding to a graph without loops has all zero entries. The relationship between a graph and the eigenvalues and eigenvectors of its adjacency matrix is studied in spectral graph theory. The adjacency matrix of undirected simple graph is symmetric and therefore has a complete set of real eigenvalues and an orthogonal eigenvector basis. The set of eigenvalues of a graph is the spectrum of the graph. If A is the adjacency matrix of the directed or undirected graph S, then the matrix An (i.e. the matrix product of n copies of A) has an interesting interpretation: the entry in the row i and column j gives the number of (directed and undirected) walks of length n from vertex i to vertex j. This implies, for example, that the number of triangles in an undirected graph S is exactly the trace of A3 divided by 6.

4. OBJECTIVE

The objectives of the present research work are as following:

- Identification of important parameters affecting the surface roughness in a roller burnishing process.
- Analysis of the effect of individual parameter on the surface roughness value.
- Identification of the most critical parameter affecting the surface roughness value.

- Comparison of different roller burnishing processes.

5. IDENTIFICATION OF PERTINENT ATTRIBUTES AND THE FACTORS

(i) Feed direction:

Feed direction means the direction in which the tool approaches the workpiece. There are two types of feed direction: (a) along b) counter.

a) Along:

It implies that the tool is moving in the direction of workpiece.

b) Counter:

It implies that the tool and work piece are moving in the opposite direction.

By the study of literature, it was found that surface roughness will improve more in case of counter feed direction. **(ii)** Work piece materials: By the study of literature, we found that the Roller Burnishing process has been applied to different materials. RB has a positive effect on the surface roughness of O1 alloy steel. The improvement percentage on the surface quality was 12.5% [4] **(iii)** Spindle Speed: The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM). The preferred speed is determined by working backward from the desired surface speed (m/min) and incorporating the diameter (of work piece or tool).Excessive spindle speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct spindle speed for the material and tools will greatly enhance tool life and the quality of the surface finish. In general, an increase in burnishing speedup to about 100 m/min leads to a decrease in mean roughness. With a further increase in burnishing speed mean roughness gradually increases. The deterioration of the surface roughness in the burnishing process at high burnishing speeds is believed to be caused by the chatter that results in instability of the burnishing tool across the work piece surface. In addition, the low surface roughness can be interpreted by the low deforming action of the rollers at high speeds and also because the lubricant loses its effect due to the insufficient time for it to penetrate between the roller and the work piece surfaces. It is better than to select low speeds because the deforming action of the burnishing tool is greater and metal flow is regular at low speed.

(iv). Feed Rate:

Feed rate is the velocity at which the tool is fed, that is, advanced against the workpiece. It is expressed in units of distance per revolution for burnishing process. Feed Rate is dependent on the:

- Surface finish desired.
- Power available at the spindle.
- Rigidity of the machine and tooling setup.
- Strength of the work piece.

The surface roughness is increased with increasing the feed rate up to certain point (0.06 mm/rev) then it begins to decrease, it is also observed that higher reduction in surface roughness happened at very low burnishing feed rate [5].

(v). No of passes:

It was found that the number of burnishing tool passes is an important parameter for the surface roughness and hardness of burnished components. The surface roughness can be increased with increasing the burnishing force or by number of passes to certain limit. The surfaces starts to deteriorate, as the surface of the metal is over work hardened due to the plastic deformation caused by the burnishing force or the number of tool passes exceeding the limits

(vi). Coolant:

A coolant is a fluid which flows through a device to prevent its overheating, transferring the heat produced by the device to other devices that use or dissipate it. An ideal coolant has high thermal capacity, low viscosity, is low- cost, non-toxic, and chemically inert, neither causing nor promoting corrosion of the cooling system.

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6. METHODOLOGY

The Graph theoretic approach evaluates the permanent qualitative index of Roller burnishing in terms of single numerical index, which takes into account the individual effect of various surface roughness parameters and their interdependencies while analysing and evaluating the RBSR. The various steps of the proposed approach, which would be helpful in evaluation of the RBSR, are enlisted in sequential manner as below;

1. Identify the various parameters of the RB affecting the Surface Roughness of the workpiece.

2. Develop a digraph among the RBSR parameters based on interactions among them.

3. Develop a performance parameter matrix on the basis of digraph developed in step2. This will be of size M × M, with diagonal elements representing surface roughness parameters and the off-diagonal elements representing interactions among them.

4. Develop a variable permanent matrix (VPMRB).

5. Find the value of permanent function for the surface roughness parameters of RB.

6. Compare different roller burnishing process in terms of surface roughness parameter permanent function obtained in step 5.

7. Document the results for future analysis/reference. Based on the methodology discussed above, the organization can evaluate the extent of parameters present in roller burnishing.

7. RESULTS AND DISCUSSIONS

- Graph Theory and Matrix Method is a multi-attribute decision making method (MADM) which is successfully applied on the roller burnishing process.

- By the application of Graph Theory and Matrix Method, we have identified the critical parameter affecting the surface roughness of roller burnishing process. In the present work, number of passes is the most critical parameter having value of maximum variable permanent function = 85725.

- Graph Theory and Matrix Method is used in the selection of an improved process among various roller burnishing processes by the comparison of variable permanent functions of the different processes.

- The Graph Theory and Matrix Method is used in the arrangement of the parameters according to their relative importance in the process. The sequence of parameters in our work is number of passes, feed direction, workpiece material, feed rate, coolant, burnishing speed.

- If some improvement is done in the parameters affecting the surface roughness of the process, then we can compare the improved process with the previous process.

8. FUTURE SCOPE

- Mathematical modeling may be done to find out the more inter-relations which would lead to the more accuracy in the calculation of permanent function value.

- The roller burnishing process can be divided into different subgroups such as surface roughness, hardness, stress value etc. and different values of permanent functions can be evaluated.

- Graph theoretic approach can be applied on various machining process.

- Complex manufacturing processes can be compared by the application of graph theoretic approach by comparing their permanent function values

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