IJARIIT
INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 3)
Available online at: www.ijariit.com

Analysis on effect of ball burnishing processes of EN24 Steel

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ABSTRACT

In the quality assurance of machine components, the so-called finishing and super finishing processes have important roles. During recent years, the post-machining cold forming methods such as burnishing, shot peening and others have occupied a very important place in the industry. Burnishing, which is one of the effective methods used to improve the surface layer properties, is essentially a cold forming process in which the raised micro-irregularities on the surface layer are plastically moved and pressed into the micro cavities. The process is carried out with a highly polished ball or roller type tool which is traversed by force over a rotating work piece. Machines normally used for burnishing operation can be drill presses, lathes, boring machines, and automatic bar or chucking machines.

The process of burnishing can be done on parts which are turned, bored, reamed or ground. Any ductile or malleable material with hardness less than 40 HRC can be successfully burnished. Although diamond burnishing machines are available for finishing material harder than 40 HR. the burnishing process is used to improve the shape of components besides producing a good surface finish. Quite the opposite, the burnishing tool will not correct deviations from roundness or Straightness to any degree.

In this work, an attempt is made to compare the results of ball burnishing (in abrasive paste conditions). The parameters taken into consideration are burnishing speed, burnishing feed, burnishing force, ball material and number of passes. Mathematical models have been developed in terms of surface roughness and surface hardness for ball burnishing process.

Keywords: *Burnishing, Ball burnishing, Surface roughness, Surface hardness, F, N, S, f.*

1. INTRODUCTION

A surface machined by conventional machining processes such as milling and turning consists of inherent irregularities produced by the cutter, or a finer structure due to tear in of the material during machining. There are many finishing processes used to produces surfaces with high-quality textures.

These processes can be classified into chip removal process, such as grinding, and chip fewer processes such as burnishing.

Burnishing is a cold working process and chip less machining process carried out to improve surface roughness, surface hardness, fatigue, and compressive strength and corrosion resistance. The Burnishing process smoothed out peaks and valleys on the surface. This is very simple and an effective method for improvement in surface finish, it can be carried out using carried existing machines, such as a lathe. The functional performance of a machined component such as fatigue strength, load-bearing capacity, friction etc. depends to a large extent on the surface as topography, hardness, nature of stress and strain

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induced on the surface region. During recent years, considerable attention has been paid to the post-machining metal finishing operations such as burnishing which improves the surface characteristics plastic deformation of the surface layer by producing compressive residual stress on the surface. During burnishing the micro irregularities start to deform plastically Initially at the crests are subjected to plastic deformation, the valleys between the micro-irregularities start to move in the direction of the newly formed surface, i.e. towards the surface in contact with the tool. The grain structure is then condensed, producing a hard surface with superior load-carrying and wear-resistant characteristics.

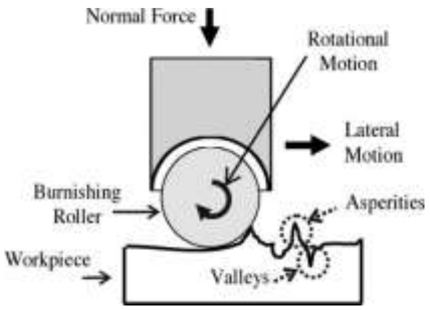

Fig1 Schematic representation of roller burnishing process

There are several forms of burnishing processes, the most common are

- Ball burnishing and
- Roller burnishing.

1) Ball burnishing

In this method, machined surfaces are burnished by a ball burnishing tool. The experimental work is carried out on a lathe machine or milling machine.

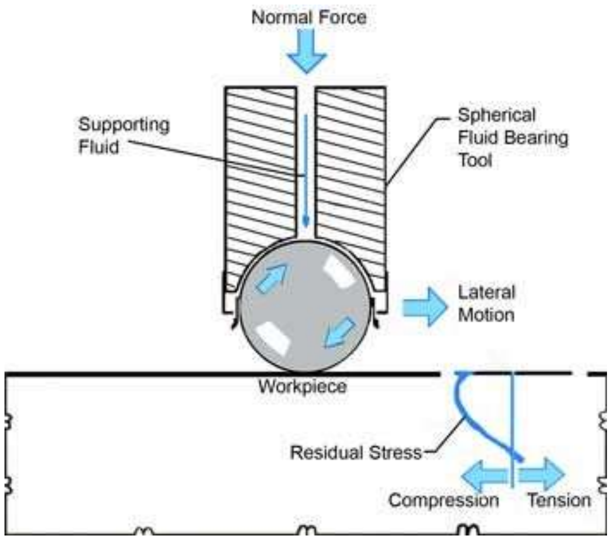

Fig 2 Ball burnishing process

2) Roller Burnishing

Roller burnishing is a cold working process which produces a fine surface finish by the planetary rotation of hardened roils over a bored or turned metal surface. Roller burnishing involves cold working the surface of the work piece to improve surface structure. Since all machined surfaces consist of a series of peaks and valleys of irregular height and spacing, the plastic deformation created by roller burnishing is a displacement of the material in the peaks which cold flows under pressure into the valleys. The result is a mirrorlike finish with a tough, work hardened, wear and corrosion resistant surface.

Need for Burnishing: Most of the finishing techniques which are in use such as precision finishing techniques like lapping, honing, super finishing, ultrasonic impact grinding and Non-precision finishing techniques such as polishing, buffing, power brushing, tumbling, vibratory finishing, shot and sandblasting only increase the surface finish of the components when it is carried out. But in burnishing in a single operation. Both the surface finish and hardness will increase which is not possible in any other finishing techniques. Hence, this technique became popular among researchers to continue work. So, in this work, it was decided to study about burnishing effect on EN24 components.

Mechanics of Burnishing: To understand burnishing, let us consider the simple case of a hardened ball on a flat plate. If the ball is pressed directly into the plate, stresses develop in both objects around the area where they contact. As this normal force increases, both the ball and the plate's surface deform.

The deformation caused by the hardened ball is different depending on the magnitude of the force pressing against it. If the force on it is small, when the force is released both the ball and plate's surface will return to their original, un-deformed shape. In this case, the stresses in the plate are always less than the yield strength of the material, so the deformation is purely elastic. Since it was given that the flat plate is softer than the ball, the plate's surface will always deform more. If a larger force id used, there will also be plastic deformation and the plate's surface will be permanently altered. A bowl-shaped indentation will be left behind, surrounded by a ring of raised material that was displaced by the ball.

If the external force on the ball drags it across the plate, the force on the ball can be decomposed into two component forces: one normal to the plate's surface, pressing it in, and the other tangential, dragging it along. As the tangential component is increased, the ball will start to slide along the plate. At the same time, the normal force will deform both objects, just as with static situation. If the normal force is low, the ball will rub against the plate but not permanently alter its surface.

The rubbing action will create friction and heat, but it will not leave a mark on the plate. However, as the normal force increases eventually the stresses in the plate's surface will exceed its yield strength. When this happens the ball will flow through the surface and create a trough behind it. The flowing action of the ball is burnishing.

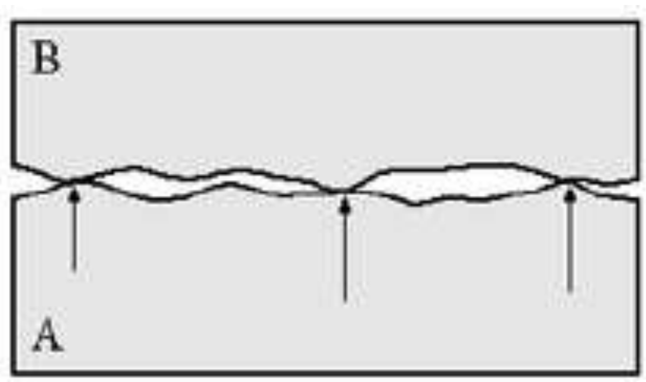

Fig 3 burnishing between two plates

Burnishing also occurs on surfaces that conform to each other, such as between two flat plates, but it happens on a microscopic scale. Even the smoothest of surfaces will have imperfections

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that extend above the general from of a surface are called asperities, and they can flow material on another surface just like the ball dragging along the plate. The combined effect of many of these asperities produces the smeared texture that is associated with burnishing.

The typical range of surface finish obtained by various surface finish methods

The following shows the various surface finish methods and their surface finish ranges.

Table I Typical range of surface finish, Ra, µm

Process	Average applications
Grinding	0.1 to 1.6
Lapping	0.05 to 0.4
Honing	0.1 to 0.8
Buffing	0.05 to 0.5
Super finishing	0.05 to0.2
Burnishing	0.2 to 0.8

In this chapter, the topics discussed are selection of process parameters, burnishing tool and machine used to conduct experiment etc., the work piece material, lubricants etc., and specifications regarding the method of burnishing, the design of the experiments.

Selections of process parameters:- It is required to choose the process parameters, also called as input variables or controlled variables. The very nature of the design dictated the type of the input variables. As these are to monitored continuously and should be able to maintain at exactly at the desired upper and lower levels through the experimental runs a judicious selection of these parameters is important. From literature survey it can be seen that the burnishing process can be controlled by different parameters such as burnishing speed, burnishing feed, burnishing force, and Number of passes etc. as we developed roller burnishing tools to suit for working in lathe machine we have taken the parameters in accordance with controllable factors in lathe machine, as we can control the burnishing speed i.e. spindle speed, also we can set the value of burnishing feed and no of tool passes which is easy to change during need of experiments we have taken the factors in our experiments. Also, the spring which we have used in tools can measure the force which we had applied on at the work piece during machining so we take the burnishing force as one of the factors in consideration. So, totally as per requirement of work and the sources available we have taken four factors into account such as

- burnishing speed, (rpm),
- burnishing feed, (mm/rev),
- burnishing force, (Kgf) and a number of passes.

Work Piece Material: EN24 Steel EN24 is a popular grade hardening alloy steel due to its excellent machinability. EN24 is used in aircraft, automobiles components such as gear, shaft, studs, and bolts.

Table II Chemical composition and properties of the work piece material EN24 Steel

Material Identification	Percentage Proportion
Carbon	0.09
Silicon	0.208
Manganese	0.479
Sulphur	0.015
Phosphorus	0.017
Chromium	0.95
Molybdenum	0.209
Nickel	1.45

Table III mechanical properties of the work piece

EN24 STEEL	
Tensile Strength (Mpa)	850-1000
Yield Stress (Mpa)	680
Hardness (HB)	248/302

Ball material: The specification of the ball, which is used in the tool is as follows,

The ball is made up of a tungsten carbide. The tungsten carbide ball used here is harder than the EN24 steel and causes plastic deformation hen pressed or forced against EN24 steel material.

Experimental set up on the lathe:- By reviewing the literature, papers it came to know that the burnishing process can be performed either by lathe or using vertical machining centers such as milling machines. In this project, the lathe is used to perform the burnishing process because it a machine in which various operations can be carried out and also the burnishing is such a process which can be carried out successively on the easily available machines such as a lathe. As it was decided on the lathe machine to perform burnishing process, were developed in ball forms. It is a universal machine compare to all other machines. The burnishing tool attachments can be easily mounted on the tool post without any extra set up. The lathe which is used here is engine lathe all geared has unique option to set the parameters as per the requirements in this work to perform the experimental runs.

2. EXPERIMENTAL PLANNING

Since it was decided to improve the surface hardness and surface finish of the materials, EN24 steel is used, which have wide application in day-to-day life. The primary reason for selecting EN24 steel is its wide range of application in automobile industry. Even though this material is hard, the automobile industry requires it to be even harder. The metal EN24 steel is widely used in automotive industry, therefore it requires burnishing process to fulfill the criteria of high hardness and good surface finish. Thus, a special ball burnishing tool was designed for this purpose and tested. The Ball burnishing tool consists of Upper body, lower body, Carbide ball holder, Carbide rod holder, Spring, Carbide ball, Tension screw. The body of the tool is made up of EN12 Steel, ball and ball holders are made up of Tungsten Carbide material, spring and tension screws are made of hardened steel. The carbide rod was reduced into two pieces of 20mm each and V-shaped groove was made on top of one of the cut ends of the carbide rod, to mount the ball in it. To fabricate the body, the EN12 Steel was machined into size. The lower body consists of spring and tension screw. Tension screw is used to obtain the required tension in the spring. The carbide rod holder was mounted on the spring on which carbide

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ball holder was fixed, on top of which carbide ball was mounted. These components were enclosed by the upper body. The developed tool used to carry out burnishing process with paste abrasives on EN24 steel.
The input parameter also known as factors, chosen were:

- Burnishing speed, rpm (S)
- Number of passes (N)
- Burnishing force, Kg (F)
- A number of passes (N).

The spring stiffness was calibrated and the results were noted down. From the calibrated result, we found that for 1mm rotation of the tool post,2.5kg of force was applied to the work piece. A carbide tip tool was used to turn the EN24 steel work piece, as this is the hardest material present. 40 tests were conducted altogether on EN24 steel. Then the 40 work piece of each material were divided into two batches of 20 samples. in that one batch were turned at 250RPM, 0.1 mm/rev Feed and 1 mm Depth Of Cut. 20 samples were further divided into a batch of 10 samples. One batch of samples was subjected to ball burnishing process using fine abrasives and another batch was subjected to ball burnishing process using medium abrasive. Another batch of 20 sample was turned at 250RPM, 0.1 mm/rev Feed and 1 mm Depth Of Cut. 20 samples were further divided into a batch of 10 samples. One batch of samples was subjected to ball burnishing process using fine abrasives and another batch was subjected to ball burnishing process using medium abrasive. Burnishing was conducted using the above-mentioned parameters.

First set of 5 samples were processed by keeping the values]of Feed, Speed, and Number of passes as constants. Here the Force value was varied for each sample.

The second set of 5 samples were burnished by keeping the values of Feed, Force, Speed as constants and Number of passes were varied for each sample. The process is done for the both of the turned samples.

These experiments are conducted on EN24 Steel with fine abrasive and medium abrasive.

The output parameters, also known as effects, chosen are**:**

- Surface finish.
- Micro hardness.

All the experiments were carried out using tungsten carbide ball of 10mm diameter. Silicon carbide paste was used as an abrasive in case of experiments with abrasives. Keeping three parameters fixed at one level, the effect of variation of the other parameter was studied.

3. EXPERIMENTATION

The experimental work is covered in this chapter. As mentioned earlier the whole work is divided into two stages. Those are burnishing with fine abrasive and medium abrasive on EN24 Steel.– stage 1, stage 2.
Thus the whole experiment comprises: -
Stage 1: where the experiment is carried out by ball burnishing tool with fine abrasive paste.
Stage 2: where the experiment is carried out by ball burnishing tool with medium abrasive paste.
The experimental work involved the following steps:

1. Calibration of the spring which is used in the tool for the sake of force measurement and tool specification.
2. Preparation of the required no. of work pieces on which to do burnishing as decided earlier.
3. Making the system ready for the experiment.
4. The actual running of experimental runs as per the input parameters.
5. 'Relieving' the system.

Each one of these steps is in detail in the following tables.

Turning Parameters

Condition	Speed	Feed	Doc
Case 1	250 rpm	0.1 mm/rev	1 mm
Case 2	500 rpm	0.1 mm/rev	1 mm

Table IV The following table will give the details of experimental planning

Exp no	Constant Parameters With levels	Varying parameters
1-5	f, S, N (0.119,585,3)	F 1-5 (5,15,25,35,45)
6-10	F, S, N (15, 585, 3)	N 1-5 (1, 2, 3, 4, 5)

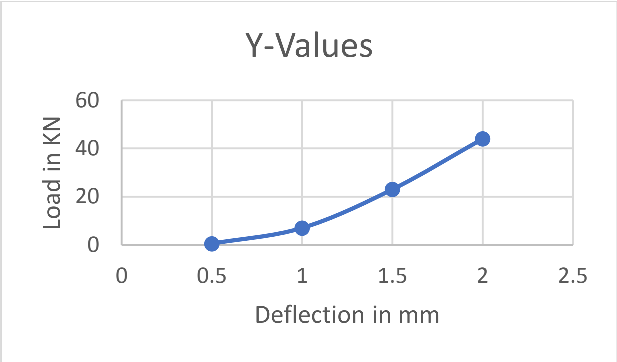
Table V

EXP NO	FEED (f) 'mm/rev'	Force (F) 'KG'	SPEED (S) 'RPM'	NUMBER OF PASS
1	0.119	5	585	3
2	0.119	15	585	3
3	0.119	25	585	3
4	0.119	35	585	3
5	0.119	45	585	3
6	0.119	15	585	1
7	0.119	15	585	2
8	0.119	15	585	3
9	0.119	15	585	4
10	0.119	15	585	5

Burnishing tool: The ball burnishing tool used in this process in a self designed and fabricated. A burnishing tool with interchangeable adopter is designed and fabricated for the experimental tests.

Fig 4 Burnishing tool

Calibration of tool Spring:



load, kg vs. deflection, mm Fig 5 graph between

From the graph it is given that,
Spring Stiffness = Load/Deflection
= 0.49/20 = 0.024525KN/mm=
(0.024525x1000)/9.81 = 2.4975= **2.5Kg/mm**

Preparation of work pieces for burnishing:- The cylindrical EN24 steel rod which was not available in as required sizes, so they were cut by using hack saw cutting hand tool to required sizes with allowance for facing etc. at the faces. The EN24 Steel rod size chosen was 18mm dia of 25mm lengths each. The work pieces are made to convenient size to work by between the center methods. The preparation of the work pieces involved following steps.

- The cylindrical EN24 is marked by chalk to cut 40+1(turning) =41 pieces.
- The EN24 Steel rods are marked to the required length by manually by keeping necessary allowance.

- The cut pieces are first made to undergo facing operation.
- The cut pieces are drilled at both ends so as to do between center methods.
- Similarly, 82 pieces were made ready to conduct the experiments as per plan.

Making the system ready for the experiment:

This was done as depicted below:

- First, the prepared EN24 Steel pieces for an experimental run is to check for its correctness i.e number wise.
- Once it was cleared with work pieces next is to check with the lathe and its parameters, the lathe is first checked with its operation, the feed, speed setting must be exact.
- The burnishing tool is adulated at the tool post and tested for the application of force on the work pieces.
- The force application measurement must be exact. The giving depth of penetration is nothing but the force applied on to the work piece.
- After setting all it is helpful to check the burnishing initially on two or three of brass pieces just for checking the setup.
- If it is found ok in above step then it was concluded that the whole system i.e. work pieces, burnishing tools and Turn master- 400 lathes are ready to conduct an experiment.

Fig 6 Ball burnishing operation for EN24 Steel

Fig 7 Surface finish testing

Fig 8 Rockwell Hardness Machine

4. OBSERVATIONS AND RESULTS

As per the objectives set in the current work, firstly we have turned the work piece of EN24 by setting the moderate range of parameters and tested for its Surface Roughness and Surface Hardness and obtained the results as per the following table.

Table VI Surface roughness values for EN24 Steel sample (Reference)

Ra in microns (µ)			
0º	**120º**	**240º**	Avg Ra
1.576	1.463	1.510	1.563

Average surface roughness value of EN24 Steel sample taken was 1.563 microns and it was the selected reference for the turned work piece.

Table VII Micro hardness values for EN 24 Steel Sample (Reference)

0º	**120º**	**240º**	**ROCKWELL HARDNESS NUMBER HRC**	**VIKERS HARDNESS NUMBER VHN**
23	24	23	23.3	248

From the table VII average micro hardness value of EN24 Steel sample taken was 248 VHN and it was selected reference for the turned work piece.

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Table VIII Design matrix Micro Hardness for EN24 Steel with fine abrasive

Turning Parameter Condition	W/P NO	Expt no	f ‘mm/rev’	F ‘KG’	S ‘RPM’	N	HRC	VHN
Case 1	1	1	0.119	5	585	3	31	292
		2		15		3	31.6	285
		3		25		3	31	292
		4		35		3	31	295
		5		45		3	32.3	303
	2	6		15		1	29	277
		7		15		2	31	292
		8		15		3	29	277
		9		15		4	32.6	303
		10		15		5	30	285
Case 2	3	11	0.119	5	585	3	30	285
		12		15		3	31	292
		13		25		3	32.6	303
		14		35		3	34	320
		15		45		3	38	361
	4	16		15		1	33	311
		17		15		2	34	320
		18		15		3	32.3	303
		19		15		4	31	292
		20		15		5	32	303

Table IX Design matrix Micro hardness value for EN24 Steel with medium abrasive

Turning Parameter Condition	W/P NO	Expt no	f ‘mm/rev’	F ‘KG’	S ‘RPM’	N	HRC	VHN
Case 1	5	1	0.119	5	585	3	32.6	303
		2		15		3	33.3	311
		3		25		3	32	303
		4		35		3	36.3	342
		5		45		3	38	361
	6	6		15		1	34	320
		7		15		2	31.6	292
		8		15		3	38.6	361
		9		15		4	32.6	303
		10		15		5	34	320
Case 2	7	11	0.119	5	585	3	34.6	320
		12		15		3	30.3	285
		13		25		3	35	332
		14		35		3	35.3	332
		15		45		3	37	357
	8	16		15		1	30	285
		17		15		2	33.3	311
		18		15		3	34	320
		19		15		4	33.3	311
		20		15		5	33.3	311

Table X Design matrix Micro Roughness for EN24 Steel with fine abrasive

Turning Parameter Case	W/P NO	EXP NO	(f) ‘mm/ rev’	(F) ‘KG”	(S) ‘RPM”	(N)	Ra microns
Case 1	1	1	0.119	5	585	3	085
		2		15		3	0.886
		3		25		3	0.795
		4		35		3	0.933
		5		45		3	0.993
	2	6		15		1	0.684
		7		15		2	0.703
		8		15		3	0.893
		9		15		4	0.959
		10		15		5	0.989
Case 2	3	11		5		3	0.88
		12		15		3	0.66
		13		25		3	0.513
		14		35		3	0.542
		15		45		3	0.676
	4	16		15		1	0.519
		17		15		2	0.611
		18		15		3	0.509
		19		15		4	0.515
		20		15		5	0.436

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Table XI Design matrix Micro Roughness for EN24 Steel with fine abrasive

Turning Parameter Case	W/P NO	EXP NO	(f) 'mm / rev'	(F) 'KG"	(S) 'RPM"	(N)	Ra microns
Case 1	5	1	0.119	5	585	3	0.543
		2		15		3	0.496
		3		25		3	0.76
		4		35		3	0.59
		5		45		3	0.608
	6	6		15		1	0.859
		7		15		2	0.73
		8		15		3	0.61
		9		15		4	0.471
		10		15		5	0.551
Case 2	7	11		5		3	0.464
		12		15		3	0.504
		13		25		3	0.565
		14		35		3	1.13
		15		45		3	1.335
	8	16		15		1	1.184
		17		15		2	0.903
		18		15		3	0.466
		19		15		4	0.588
		20		15		5	0.588

5. CONCLUSION

- Ball burnishing is an effective method for improving both surface finish and micro hardness.
- During ball burnishing process of EN24 steel with fine abrasive condition least value of surface finish that got 0.436 microns and percentage decrease of surface finish is 72.104% and maximum micro hardness that got 361 VHN and percentage increase in hardness is 45.564%.
- During with medium abrasive least value of surface finish got 0.464 microns and percentage decreases when compared to the turned work piece is 70.313% and maximum micro hardness that got 362 VHN and percentage increase in hardness is 45.234%.

6. ACKNOWLEDGEMENT

The credit of the completion of the project work goes behind our own work, to those people who have always been with us through out and we take this opportunity to express our heart-felt gratitude to each one of them.

We wish to thank our guide **Mr. Pavan Kumar**, Assistant professor, Department of Mechanical Engineering, Shri Madhwa Vadiraja Institute of Technology and Management, Bantakal for being a constant source of inspiration, encouragement and providing proper technical guidance at all stages of the project.

We are thankful to **Dr. Sudharshan** Rao K, H.O.D, Department of Mechanical Engineering, Shri Madhwa Vadiraja Institute of Technology and Management, Bantakal for allowing us to carry out this project and for ensuring all the facilities required to carry out this project.

At the outset we take this opportunity to thank Prof. **Dr.Thirumaleshwar Bhat**, Principal, Shri Madhwa Vadiraja Institute of Technology and Management, Bantakal for his guidance and encouragement for completion of this project.

We would like to thank **Mr Jayesh Vasavi** (Hi Tech Sales Corporation, manglore) for providing materials which are needed for project.

We would also like to thank **Mr Stanley M Kotian** (SEATO TECHNIQUES) for helping us to build a tool of our requirement.

We specially thank **Mr Raghuram Shettigar**, Instructor and also we thank all the teaching and non-teaching staff Department of Mechanical Engineering, Shri Madhwa Vadiraja Institute of Technology and Management, Bantakal for helping us in completion of the project work.

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