Design of special purpose grinding machine structure for Back-Gouging of T-Joint Weld Groove for Full Penetration Welding

By

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INSTITUTE OF TECHNOLOGY

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Design of special purpose grinding machine structure for Back-Gouging of T-Joint Weld Groove for Full Penetration Welding

Major Project Report

Submitted in partial fulfilment of the requirements

For the degree of

Master of Technology in Mechanical Engineering (CAD/CAM)

By

Ayush Prajapati (22MMCC10)

Guided by

Prof. N.D. Ghetiya

DEPARTMENT OF MECHANICAL ENGINEERING

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NIRMA UNIVERSITY

2024

Declaration

This is to certify that

1. This thesis comprises my original works toward the degree of Master of Technology in Mechanical Engineering (CAD/CAM) at Nirma University and has not been submitted elsewhere for a degree.
2. Due acknowledgment has been made in the text to all material used.

Ayush Prajapati

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This is to certify that the Major Project report, entitled **Design of special purpose grinding machine structure for Back-Gouging of T-Joint Weld Groove for Full Penetration Welding,** submitted by **Ayush Prajapati (Roll No: 22MMCC10)** towards the partial fulfilment of the award degree of Master of Technology in the field of CAD/CAM, Mechanical Engineering Department, of the Institute of Technology, Nirma University is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached the level required for being accepted for the examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for the award of any degree.

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Approval Sheet

The Project entitled **Design of special purpose grinding machine structure for Back-Gouging of T-Joint Weld Groove for Full Penetration Welding** by **Ayush Prajapati(22MMCC10**) is approved for the degree of Master of Technology in Mechanical Engineering (CAD/CAM).

Examiners

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Acknowledgment

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ABSTRACT

Present work is focused on the design and analysis of automatic grinding machine for back-gouging of T-joint weld groove for full penetration weld. As a part of this work, various critical component namely, column, lead screw, bearing, and grinding machine frame are designed. The selection of materials for critical parts is based on specific requirements. The primary objective of this project is to develop an automatic mechanism of grinding machine that capable of back-gouging of T-joint weld groove without penetrate into plate. During the design process, the working envelope of the mechanism and the available shop floor space are also taken into consideration. In conclusion, this project "Design of SPM for back-gouging of T-joint weld groove for full penetration welding" has designed in such a way the individual component can withstand as per loading condition and can perform the entire operation with ease.

There is requirement for weld edge preparation, Surface finish for some NDT test and for back gouging or chip back of welding. Present work contains design of Grinding head and design of column boom for that grinding head. Whole arrangement is column beam type arrangement with several motions, so that all grinding point can be achieved by grinding head. The structural parts are designed as per requirements and analysis is carried out in software ANSYS. Finite element Method or Finite Element Analysis is an approximation technique used for the analysis of complex objects and geometries. Maximum Stress and Displacement is under the range of loading condition. Modal analysis result shows the maximum and minimum displacement occurs at the end of the bearing was 0.012 m and 0.004 m respectively, at 0 Hz and 2.82*10^-3 Hz frequency.

Key Words: Grinding Wheel, Linear and Rotary mechanism, Servo motor, Bearing, lead screw, finite element analysis

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Chapter 1

Introduction

1.1 Grinding Process

"grinding” is the process of abrasion sharp abrasive grains are used on the face or sides of bonded grinding wheels to remove material. Chips are actually removed from the task by the grains. off-hand grinding and precision grinding are the two main kinds of grinding.[1]

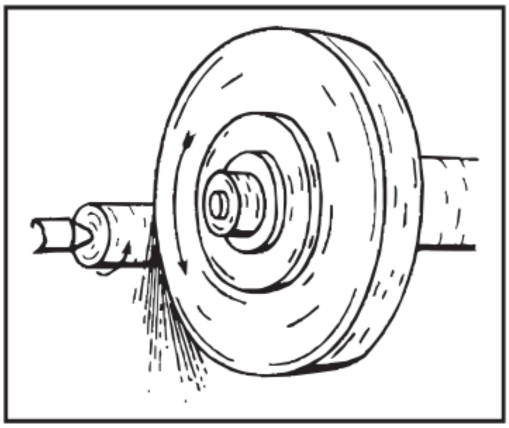


Figure 1 In fact, a grinding wheel removes chips from the object being ground [1]

1.2 Types of Grinding

1. Off hand grinding also known as non-precision grinding, is the process of applying the grinding wheel to the work by hand or offhand. Uses such as bench or pedestal grinding, cutting off, tool sharpening, weld grinding and casting.[1]
2. precision grinding refers to machine grinding in which process parameters are measured and controlled and transverse and feed rates can be adjusted. As the name suggests, Surface finish geometry, size management and other factors are more important here. Example of grinding techniques include cylindrical, centreless, internal surface, tool and cutter, thread and crankshaft grinding. [1]

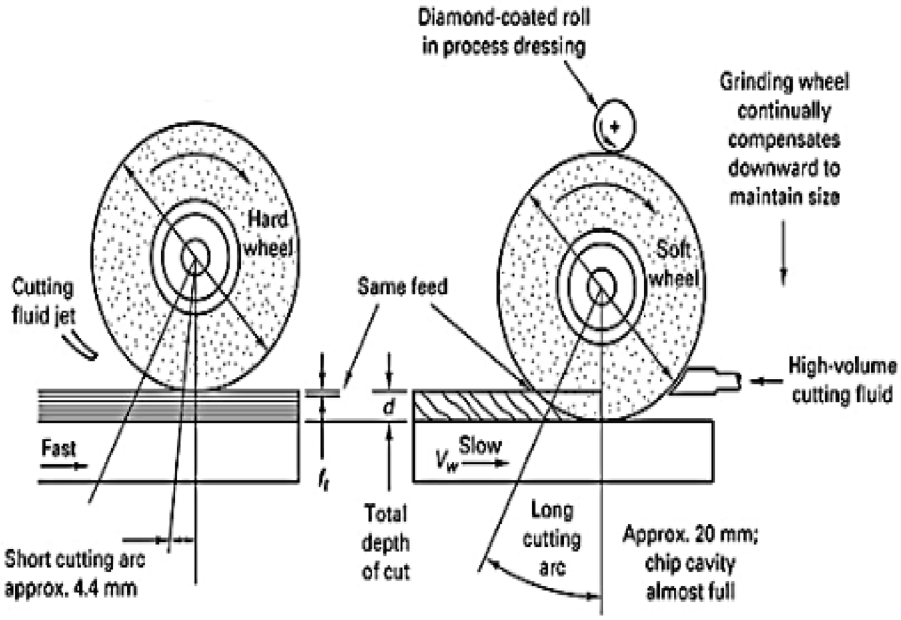


Figure 2 (1) Conventional grinding (2) Creep feed grinding [2]

1.3 Types of Grinding Machine

There are various types of grinding machines are available like, floor stand grinder, horizontal and vertical surface grinder, portable grinder, centreless grinder, etc.

1.4 Types of Grinding Wheel Shapes

- D = Diameter
- E = Thickness at hole
- F = Depth of recess
- G = Depth of recess
- H = Hole
- J = Diameter of outside flat
- W = Wall thickness of grinding face

K = Diameter of inside flat

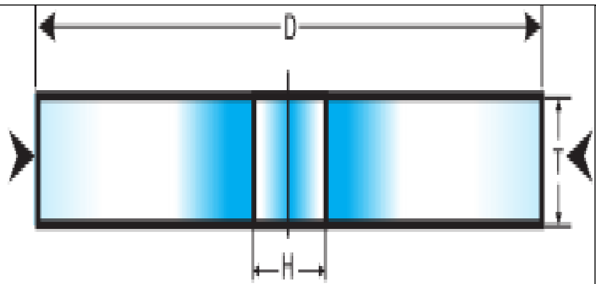
M = Large Diameter of bevel

P = Diameter of recess

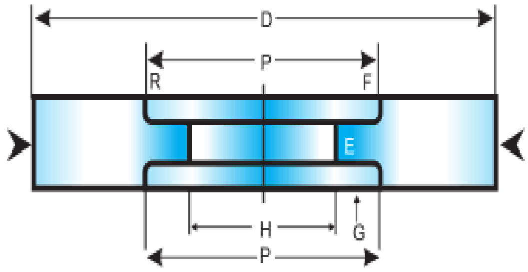
R = Radius of corner

T = Thickness (overall)

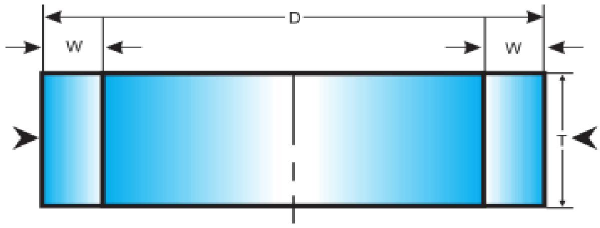
U = Width of edge



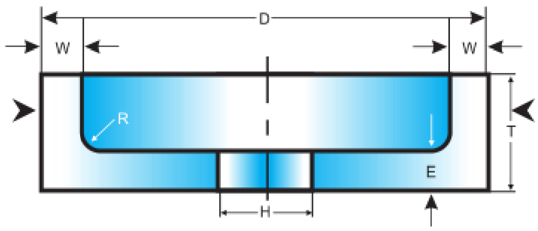
Straight Wheel (internal grinding)



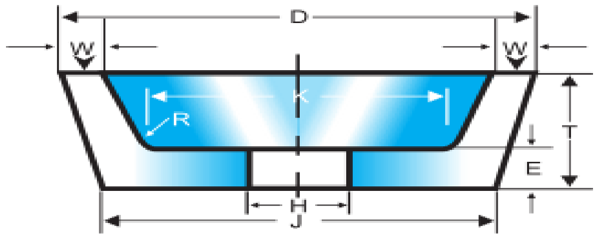
Straight Wheel (Cylindrical grinding)



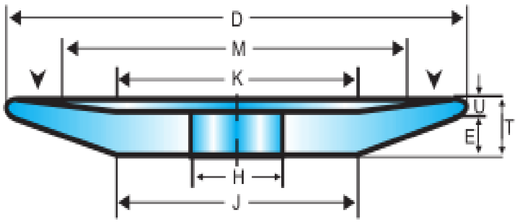
Cylinder Wheel



Straight Cup Wheel



Flaring Cup wheel



Dish wheel

Figure 3 various grinding wheel shapes[1]

Standard forms of grinding wheel faces are shown in figure 3 the types of face to be utilised depends on the nature of the work. For example, shape E is typically used for grinding threads, whereas shape A is typically used for straight cylindrical grinding.[1]

- **Selection of grinding wheels:**

  The materials hardness and to be ground surface, finishing and stock removal., The types of grinding way to dry, the wheels peripheral speed, the size of the grinding contact area, the application for grinding, the grinding machines state.

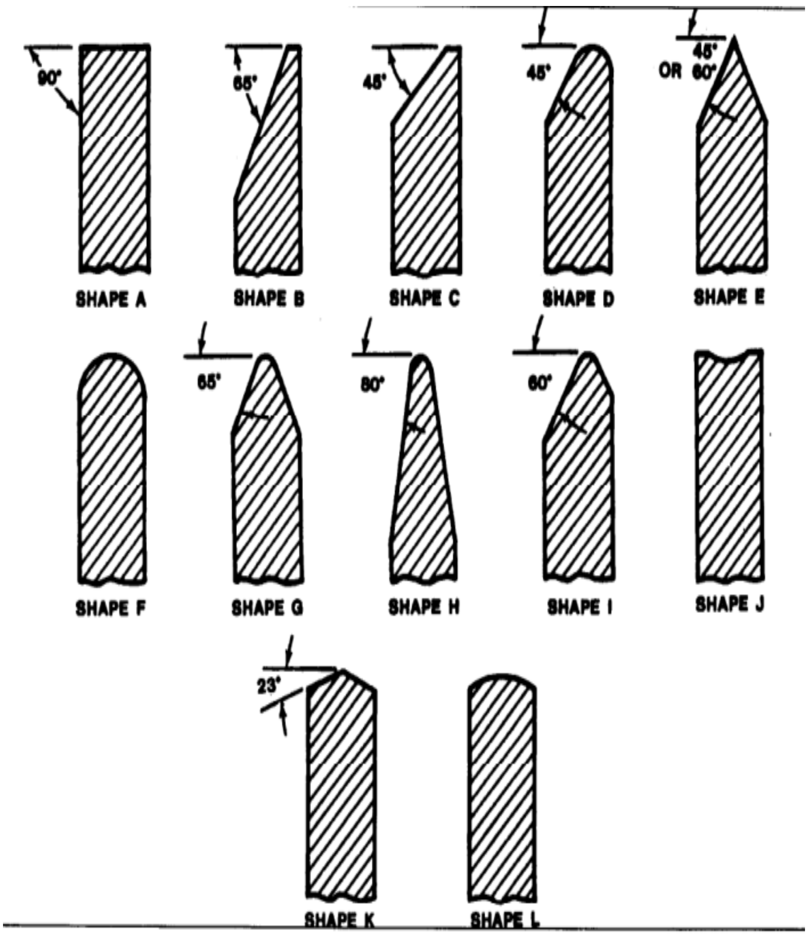


Figure 4 grinding wheel standard shapes [3]

1) The choice of abrasive, including grit size and grade, depends on the kind of material to be ground. For grinding high tensile materials like alloy steel, high speed steel, annealed malleable iron and other ferrous metals, aluminium oxide abrasive are perfect. Abrasive made of silicon carbide work wonders when it comes to cutting or grinding non-metallic materials with low tensile strength, like copper, bronze, aluminium and cast iron. The materials hardness plays a significant role in deciding the grit size. Coarser grit wheels work best on soft and ductile materials, whereas finer grit wheels are necessary for hard and brittle material. Wheel grade selection is also influenced by material hardness. The grade of the wheel is influenced by whether the operation is wet or dry. During dry grinding with vitrified wheels, in order to minimise the heat generated, soft grade wheels should be used. These can be at least one or two grades softer than the ones chosen for wet grinding operations.

   In wet grinding applications, where coolants reduce the heat, harder grade wheels can be used.
2) The wheels peripheral speed is the rate at which its grinding edge travels across the work surface. This is a crucial consideration when choosing a grinding wheel. Standard, vitrified wheels have a maximum operating speed of 60 m/s. Either the blotter or the wheel face conveys

this. in most application when a speed rate of up to 48 m/s is necessary, Organically bonded wheels made of rubber, shellac, or resign are utilised for strengthened goods, Faster speed can reach up to 100 mph. Wheel hardness decreases as wheel speed is decreased.

3) A Number of parameters, including high work speed and traverse rates, heavy feed, shock load pressure and intermittent grinding content can contribute to the severity of a grinding operation. As a result, when choosing a wheel, a grinding process affects the grade, kind and even bond of the abrasive. The harder the wheel grade needed and the rougher the abrasive that needs to be utilised, The more severe the grinding operations, for example, a harsh abrasive like A or ZA is needed for sever grinding operations like snagging. precision grinding jobs are best suited for medium and soft grade wheels.
4) Poor machines condition are often the root causes of grinding defects. These can include loose bearing, unequal or badly spliced belt, belt slippage, old gears, incorrect machine alignment, insufficient foundation or overall vibration of the machine. It is imperative that all grinding machines can be secured or mounted on sturdy level bases.

   One further crucial element is the machine's power. This has a significant impact on the stock removal rate. The cutting power and grinding wheel speed will both decrease in the event that the motor power insufficient. Elevated temperatures and excessive pressure between the wheel and the workpiece may arise from this. A wheel of a tougher grade can be employed for more efficient operation in the machine Has a high power output. It is important for the user to confirm that the wheels maximum rpm and the machines maximum rpm match. The users should never go faster than the posted speed restriction. A locking mechanism should be included on machines having programmable rotational speeds to avoid.[1]

1.5 Grinding Wheel Information:

Grinding wheel's is made by two types of abrasives. (1) Natural abrasives (2) Artificial abrasives. Grinding wheel's standard marking systems is denoted by grits, grade, structure and bonds. In abrasive structure of grinding wheel's mainly three types of substance is available like, grains, bond, and pores.

Wheel Spindle:

The wheel spindles design should accommodate the loads that it will be subjected to, as well as the specification of the grinding wheel that it will be used with (dimension, weight, speed, etc.).The wheel needs to be properly positioned on the spindle, which needs to be clear of burrs and not worn or broken. It is important to lube spindles Property to keep them from overheating while grinding.[1]

Mounting Flanges:

The wheel is clamped to the machine and the driving force is transferred from the machine spindle to the grinding wheel via the mounting flange. Depending on the machine and type of grinding wheel, Different wheel flange design are used. It is necessary to fasten the Flange to the machine spindle. In order to securely the retains the wheel, The screws or nuts used to fasten the flange must be tightened uniformly and in a diametrical sequence.[1]

Safety Guards:

Safety shields that are specifically made for the kind of wheel and grinding operations should be installed on all grinding machines. These safety guards should cover the whole wheel, excluding the grinding area and meet standard. But for some processes, even the workspace needs to be secured in the case of a wheel break, safety guard should primarily be able to contain wheel fragments and shield the operator. wheel wear should be accommodated for by adjusting this protector as well.[1]

Work Rests:

For the purpose of making it easier to guide hand-held work pieces, work rests with fixed grinding heads should be installed. In addition to being robust and stiff, they ought to be movable to accommodate wheel wear.[1]

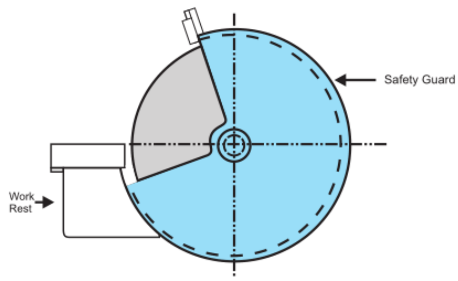


Figure 5 Safety Guards [1]

Blotters:

Blotter are crucial to a grinding wheels functionality. These are positioned between the flange and the grinding wheel and are composed of pliable, compressible material, such as cardboard or plastic with the thickness of between 0.2 and 1 mm. Typically blotters of the same size are either loose or attached to both sides of the wheel face.[1]

The purpose of using blotters are:

To serve as a barrier between the grinding wheel's abrasive surface and the metal marking plates.

To remove any distortion that may exist between the flange and the wheel in the locating area.

To remove the possibility of the wheel and Flanges slipping.

To even distribute the axial clamping force throughout the whole flange locating area after the nuts are tightened.[1]

Dressers:

A grinding wheel is dressed and trudened with dressers. To achieve the necessary geometry or form on the wheel's grinding face, truing is necessary it improves grinding efficiency and returns a grinding wheel's form and surface.[1]

Guidelines for dressing:

To ensure vibration free operation, the dresser should be held as firmly and as near to the point of dressing as feasible.

The dresser's diamond point ought to be poisoned at an angle, ranging from 3 to 10 with respect to the wheel's centre line.

Dressing should be done at regular speeds with plenty of metal working fluids in order to preserve the sharpness of the diamond point.

The dresser should be turned in the machine tool holder at an angle of 15 to 45.[1]

Figure 6 grinding wheel dressing [4]

1.6 Problem Definition:

In case manual grinding operation for back gouging of weld joint low productivity and more man power required are the major challenges. So, in case of manual grinding for back-gouging, well trained workers required for safety and ensuring quality. For large size of T-plate, the process of grinding is very difficult, so it is required to make the automatic grinding machine that can do the required work with ease and make the process easier. Enhance quality of back-gouged weld groove for full penetration weld joint to reduce weld defects. Grinding wheel not penetrate into while grinding operation.

1.7 Objective:

To design Special purpose grinding machine for grinding operation without penetrate into plate.

To do the FEA of the designed parts for vibration and modal analysis.

Chapter 2

Literature review

Experiments and simulations conducted by Yang et al. [7] investigated the buckling behaviour of welded steel box section columns. looked into the buckling behaviour of welded steel box section. Twelve medium length steel column-ten with a rectangular hollow cross section and two with a welded square section were subjected to axial compression as a part of the investigation. To depict a wide range, the width to thickness ratio of each column specimen varied. Data on material properties, geometrical defects and load displacement curves were acquired by the researchers. They discovered that the projection in the Most recent design course Eurocode3, were exaggerated when they compared with their findings with those codes. Finite element method was employed in the calculation, while carbon steel was used in the trials. The plate first displayed local buckling, which was followed by an increase in Overall displacement until total buckling happened.

Five distinct kinds of creative hollow steel section columns have been designed, produced and tested by Pawar et al.[8].The present studies Divided into two primary portions. The First part examines how a novel corrugated steel column behaves under axial loading conditions. The experimental work is the term used to describe this portion of the study. the theoretical results acquired through an analytical method and the use of the computer programme Ansys are compared with the result of the real experiment in the second section of the study. The result acquired from computer analysis and Experimental testing are compared and validated. to gain deeper comprehension of the advantage of an inventive column.

Syriac et al [12] presented Analysis of the dynamic properties of a lead screw took thread parameter. Chang into account. The study examined the behaviour of the lead screw inside the switch gears withdrawal portion of the circuit breaker By analysing it's mechanical reaction. The force transfer and overall mechanical system efficiency are significantly influenced by criteria Like, thread pitch, nominal diameter, etc. The study was conducted using a variety of thread profiles, including square, trapezoidal and ACME threads, and the result were simulated using FEA software, Specially ANSYS Workbench. Therefore, the system natural frequency is impacted by the examination of variables such as screw length, nominal diameter and worktable position. The system inherent frequency amplitude While changing the length of the screw along the stroke length.

A study on the incorporation of a ball screw and stepper motor into an electromechanical system to convert an industrial pneumatic cylinder into one that is more exact and repeatable in terms of location, speed, acceleration and force was presented by Fotuhi et al[13]. based on the position velocity and acceleration profile cylinder mechanism The mechanical and electrical efficiency has been investigated. The test equipment comprises a force and current sensor incremental and linear encoders and spring. Based on the spring's stiffness in the experimental setting, the force was computed. Three spring with various stiffness coefficient values, were utilized to assess the forces. With an a type spring, the maximum speed case produces the lowest RSME values. The maximum force value F-359 N was obtained by the ball screw mechanism and stepper motor. Out of three A, B, C, A-type has performed better.

In [14], Fu Wenhua et al, Presented a method for effectively grinding things. A Workbench with a via hole grinding disc, a revolving main shaft and an automated grinding disc installation mechanism are all part of the system. The grinding disc may be easily installed and detached thanks to the rotating mains of shaft's first working and standby position. The revolving main shaft's placement beneath the workbench streamlines the construction and makes it easier to load and unload the item. Furthermore, the grinding head's downward pulling force lessens the chance of bending and streamlines the grinding shaft's driving and structure.

Several ultra precision grinding machine developments are included W Brain Rowe[6] Describe the trends in high precision and high speed grinding, along with the principle underlying improvements in machines and processes. Numerically workload examples give scale to essential process parameter. recent research finding and original contributions to knowledge are included.

Jae-Seob Kwak1, Man-Kyung Ha [16] The relationship between the grinding ratio and static grinding force was shown, and the experimental evaluation of a wheel life varied with the ground grain sharpness and static ground force was undertaken.

Xue Feng Bi [17]a series of grinding tests are performed to obtain burn variation with grinding parameters using different grinding wheel and workpiece in order to evaluate the influence of grinding parameter on burn,

Rogelio L. Hecker, Steven Y. Liang1, Xiao Jian Wu, Pin Xia [10]A total tangential and normal forces in surface grinding and total grinding power in cylindrical grinding are predicted using probabilistic distribution of chip thickness as a function of kinematic conditions, material properties, wheel microstructure and dynamic effect.

By comparing the model's computed result with the experimental results, Jinyuan Tang1, Jin Du1, and Yongping Chen1 Have established a novel mathematical model of grinding forces in surface grinding[9]. The model is made up of sliding forces and chip formation forces.

A workbench featuring a via hole, a grinding disc that may be pushed into an interior chamber of an object to be ground, a revolving main shaft and an automated installing mechanism are described by Fu Wenhua, Ding Bangjian, and Sun Changchun [20].

With an emphasis on useful advanced analysis techniques that can be used to steel structure, Zengyuan [21] investigated the torsional and buckling analysis of steel frame components. This work provides a through investigation of analysis method appropriate for steel construction.

Based on the observation that chip formation during grinding occurs in three stages Plow, cutting and rubbing a new grinding force model is developed by U.S. Patnaik Durgumahanti1, Vijayender Singh1, P. Venkateswara Rao1[11]. this model incorporates the effect of variable coefficient of friction and ploughing force.

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Chapter 3

Design of Grinding Machine Structure

3.1 Grinding Force:

1) Creep-feed grinding force:

Method 1:

The ability to precisely grind a hard to grind material while removing material quickly is one of the primary benefits of creep-feed grinding. In general, creep-feed grinding produce less uneven chip thickness than surface grinding, which enhances the workpiece surface treatment and lessens wheel wear. Nevertheless, there are a number of drawbacks to this benefits. When creep grinding is used, they typically draw more energy and have stronger ability Consequently, compared to conventional surface grinding application, it calls for stronger machinery and fixtures, as well as spindle with greater power.

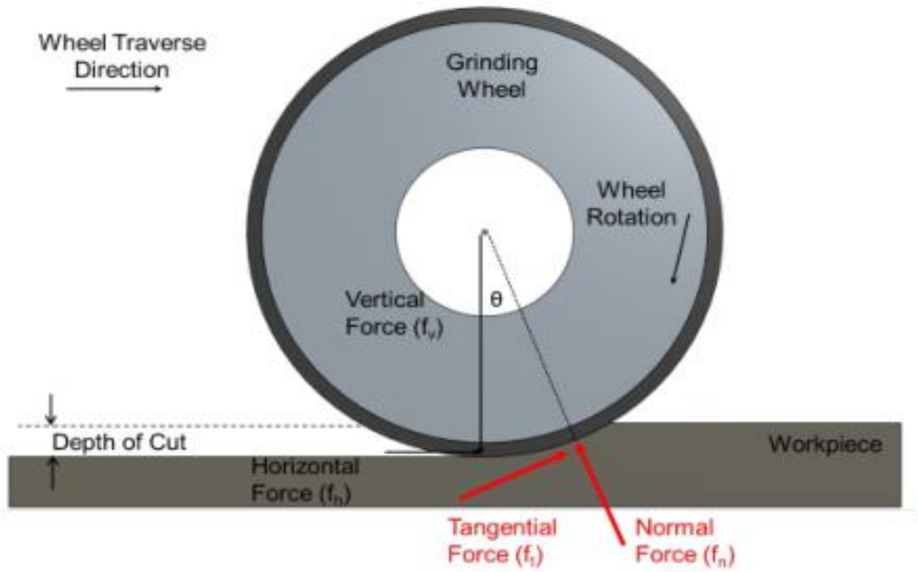


Figure 7 Schematic of simple creepfeed grinding operation [5]

Think about the straightforward 2D creep-feed grinding depicted in figure 3.1. The tangential force and the normal force are the two main forces operating on the wheel in this application.

The force operating parallel to the contact surface between the wheel and workpiece is known as the tangential force(ft), When the force acting perpendicular to the contact surface is known as the normal force(fn), the design requirements for gripping the workpiece and systems Stiffness are determined by the size and direction of the grinding forces. The direction of these forces is especially crucial in procedures where the wheel-workpiece point of the contact may shift during the grinding operation, changing the direction of the grinding forces.

$$Ft = \frac{POWER * 330000 \frac{ft*lb}{min}}{SFPM} \, lbf \qquad (1)$$

Where Vs is the wheel speed (in sfpm), ft Is the power (in horsepower). These equations can also be used to compute forces on the workpiece since at the point of contact, The tangential and normal forces on the wheel are equal and opposite to the forces acting on the workpiece. The ratio of the grinding coefficient of friction can be used to estimate the normal force after the tangential force is known.

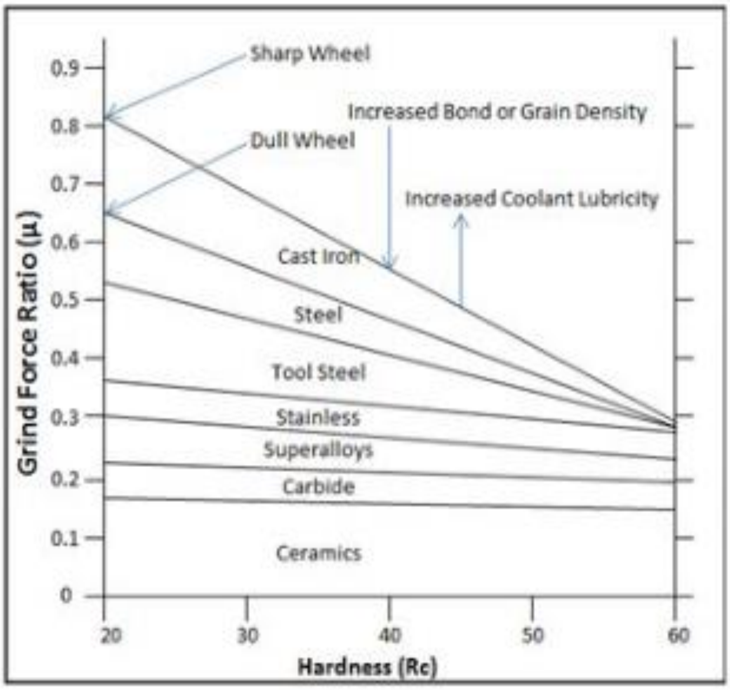


Figure 8 varying the grinding ratio according to the hardness and kind of material [5]

Once μ and F t are known, the normal force can be estimated through the

equation:

$Fn = Ft/\mu \, lbf$ (2)

Method 2:

Using a dynamometer, measured the vertical and horizontal forces generated during the grind to determine the next tangential force. Next, using the following equation, one may get the normal and tangential forces given the normal force vector angle(see fig 3.1):

$Ft = Fv \sin(\theta) + Fh \cos(\theta)$,$Fn = Fv \cos(\theta)$-$Fh \sin(\theta)$ (3)

$\theta = \sqrt{\frac{depth\ of\ cut}{wheel\ diameter}}$

2) Basic Grinding Forces parameters:

- Depth of material removed:

The actual depth of cut a_e is the fundamental grinding parameter. The machine operator configures the cut depth a_p.

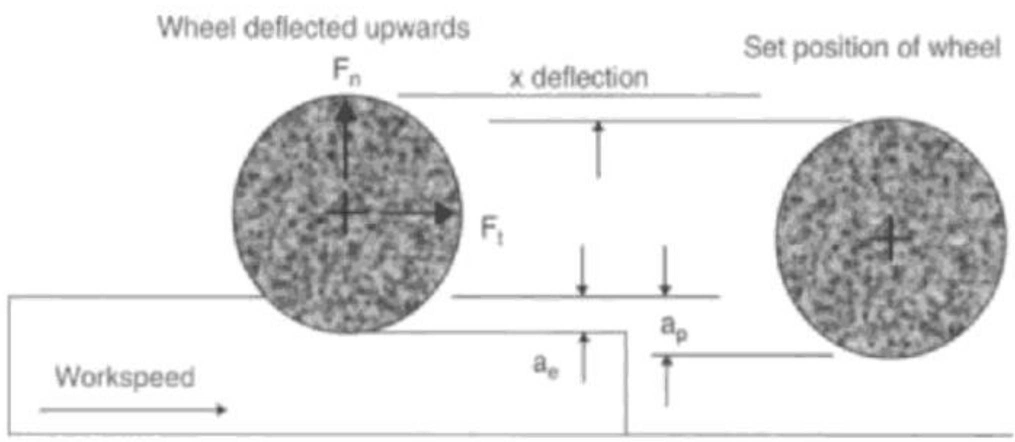


Figure 9 Grinding force effects on wheel deflection and actual cut depth [6]

$a_p = \pi * d_{w*} \frac{v_f}{v_e}$ (4)

$a_{e,}d = real\ depth\ of\ cut$

$v_s = wheel\ speed$

$v_w = work\ speed$

$a_p = programmes\ of\ depth\ of\ cut$

$b_w = grinding\ contact\ width$

$l_c = contact\ length$

$$l_c = \sqrt{D * d} \tag{5}$$

$d_{w,}D = diameter\ of\ wheel$

$v_f = in - feed\ rate$

$a_s = wheel\ wear$

$x_{exp} = thermal\ expansion\ of\ workpiece$

$$a_e = a_p - x - a_s + x_{exp} \tag{6}$$

- Stiffness Factor K

  Set depth of cut is equal to real depth of cut and deflection, ignoring wheel wear and thermal expansion. In other words, $a_p = a_e + x$.The machine stiffness factor K determines the percentage of the predetermined depth eliminated, were

  $K = \frac{a_c}{a_p}$, deflection x depends on λ, the machine stiffness, as $x = \frac{F_n}{\lambda}$

  Normal grinding force $F_n = K_s a_e$, where K_s is termed the grinding stiffness. It follows that x/a = K_s./λ. The stiffness factor is therefore given by

  K=1/(1 + ks /λ) is equal to This indicates that the real depth of cut is only half of the design depth of cut. when K_s / λ = 1, the stiffness factor K = 0.5 in real world application, it is discovered that grinding stiffness K rises in direct proportion to grinding breadth. reducing the stiffness factor K to 0.333 requires doubling K_s / λ value of 2. A stiff machine and moderate grinding forces are represented by a value of k=0.4 in finish grinding. High grinding forces and a complaint machine are indicated by a value of K=0.1. When high wheel speed and deep cuts are used in high efficiency deep grinding (HEDG), the value of K is typically substantially greater.

- Equivalent Chip Thickness:

  The thickness of the layer that emerges from the grinding zone at wheel speed is significantly less than the depth of material removed(a_e)when the material is accelerated from work speed to wheel speed its thickness would decrease to the equivalent chip thickness(h_{eq}). If it formed into a solid extruded sheet.

- Chip Thickness (h_{eq}):

$$h_{eq} = a_e \frac{v_w}{v_s} \tag{7}$$

- Material Removal Rate

In grinding, the material removal rate is commonly expressed as the removal rate per unit width of the grinding contact. Specific removal rate Q' is the removal rate per width. Direct comparison of removal efficiency across a broad variety process is made possible by the reduction of variables by using the particular removal rate.

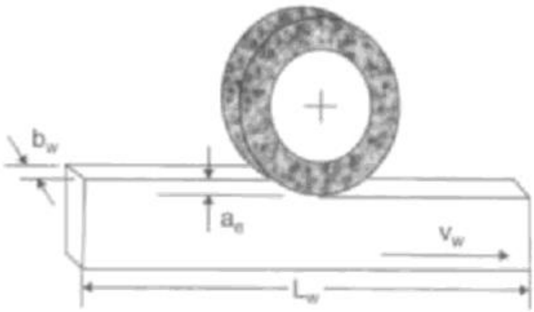


Figure 10 The specific removal rate and the removal rate [6]

- Removal rate(Q):

$$Q = b_w * a_e * v_w \tag{8}$$

- Specific removal rate(Q'):

$$Q' = a_e * v_w \tag{9}$$

- Specific grinding energy(e_c):

Grinding energy is an additional useful indicator of a grinding wheels capacity to remove material. The workpiece materials grindability and the grinding wheels sharpness determine how much grinding energy is used. The grinding power P divided by Q yields the amount of grinding energy needed to remove a certain volume of material. In the field of manufacturing technology, this amount is commonly referred to as the specific cutting energy(e). As the grinding process is under consideration, It will also be deferred to as the specific grinding energy, or just specific energy.

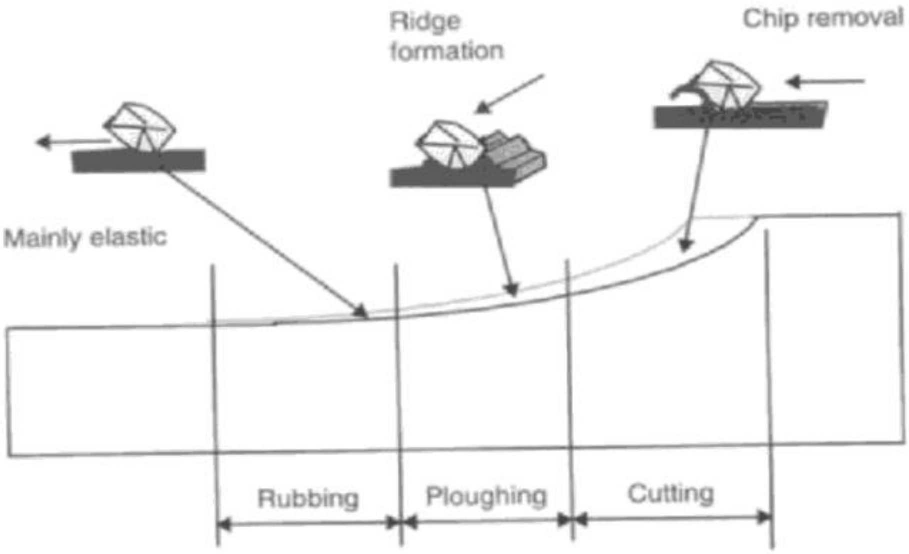


Figure 11 Distinct grain penetration via the contact arc [6]

$e_c = \frac{P}{Q}$ *where, P=grinding power* $p = F_t v_s$ (10)

Typically, specific energy ranges from 15 to 700 J/mm^3. Particularly, wheel sharpness and workpiece hardness affect the value of specific energy. A high value indicates a material that is challenging to grind, whereas a low value indicates a material that is simple to grind. Specific energy levels in HEDG that are less than 10 J/mm^3 (or 3.7 hp min/in.^{3}) could be discovered.

- Grinding Power

  Power grinding forces can also be measured in order to determine grinding power Three forces were identified during the grinding process. Tangential force(Ft), normal force(Fn) and axial force(Fa)..

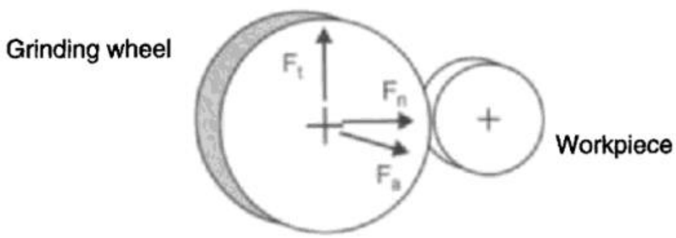


Figure 12 grinding forces [6]

Grinding power is given by $P = F_t(v_s \pm v_w) + F_n v_{fn} + F_a v_{fa}$

When grinding is done up-cut, the workpiece moves in opposition to the grinding wheels motion, when grinding is done down-cut, the workpiece moves in tandem with the wheel's motion. In actually, the workpiece speed has little bearing because V usually 60 to 200 times larger than v_w, grinding power is given rather nearly by F_t, v_s because the normal and axial feed speed, v_{fn} and v_{fa} respectively, are substantially smaller than the wheel speed v_s.

- Grinding Force ratio:

$$\mu = \frac{F_t}{F_n} \quad (11)$$

where, F_t *= tangential force,* F_n *= normal force*

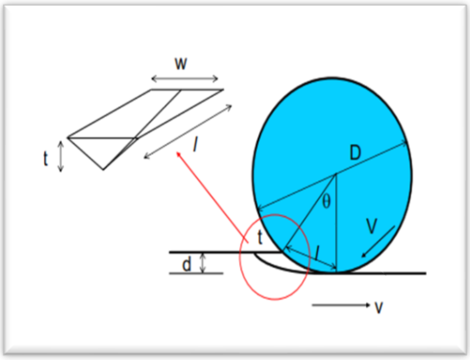


Figure 13 CHIP FORMATION GEOMATERY.[15]

As with rolling contact length, the chip length l, D = diameter wheel, d = depth of cut

$$l = \sqrt{D} * d \quad (12)$$

MRR , v = work piece velocity, d = depth of cut, b = width of cut

$$MRR = v * d * b \quad (13)$$

The chips have a triangular cross-section, and ratio (r) of chip thickness (t) to chip width (w)

$$r = \frac{w}{t} \approx 10 \text{ to } 20$$

So, the average volume per chip

$$Vol_{chip} = \frac{1}{4} * w * t * l \quad (14)$$

The number of chips removed per unit time (n), where c = number of cutting edges (grains) per unit area (typ. 0.1 to 10 per mm2 , and V = peripheral wheel velocity

$$n = V * b * c \quad (15)$$

Chip Thickness:

$$t = \sqrt{\frac{4*v}{V*c*r}\sqrt{\frac{d}{D}}} \quad (16)$$

Specific grinding energy, u:

Consist of chip formation, plowing, and sliding

$$u = u_{chip} + u_{plowing} + u_{sliding} \quad (17)$$

$u \propto \frac{1}{t}$ From empirical results, as t decreases, the friction component of u increases

Total grinding force:

Get force from power:

$$power = u * MRR \quad (18)$$

$$F_{grinding} = \frac{power}{V} \quad (19)$$

Force acting on grain :

The force per grain can be calculated:

$$F_{grain} = K_1 * \frac{1}{2} * r * t \quad (20)$$

$$F_{grain} = K_1 * \sqrt{\frac{v*r}{V*c}\sqrt{\frac{d}{D}}} \quad (21)$$

Grinding temperature:

Temperature rise goes with energy delivered per unit area:

$$\Delta T = K_2 * \frac{u * b * l * d}{b * l}$$

$$\Delta T = K_1 * K_2 * d^{\frac{3}{4}} * \sqrt{\frac{4*c*r}{4*v}}\sqrt{D} \quad (22)$$

$$K_2 = Room\ temperature$$

DESIGN OF LEAD SCREW:

Column and boom is assembled with carriage assembly, with the help of carriage assembly, boom can slide on the column. For that sliding motion there should be some mechanism between column and boom. Lead screw can convert rotary motion in linear motion. So, boom column can slide linearly on the column with carriage assembly with the help of electric motor. Nomenclature for the lead screw is shown in table 1.

Table 1 Nomenclature of lead screw

Sr No.	Description	Unit
1	major diameter of lead screw, D	mm
2	core diameter of lead screw, D_c	mm
3	mean diameter, D_m	mm
4	pitch, P	mm
5	helix angle, α	
6	coefficient of friction, μ= 0.13	
7	friction angle, φ	
8	core area of lead screw, A_c	mm^2
9	axial load, w	kg
10	load required to rotate the screw, p	kg
11	hardness, H	BHN
12	ultimate tensile strength, σ_{ut}	kg/mm^2
13	yield stress, σ_y	kg/mm^2
14	moment of inertia, I	mm^4
15	tensile stress, σ_t	kg/mm^2
16	torque, T	kg.m
17	angle of acme thread, β= 14.5	
18	thread pitch, s	mm
19	Nut thickness, H	mm
20	Number of start of thread, z	single
21	thickness at the thread base, h = 0.5 × P = 3.5	mm
22	number of engaged thread, n	

23	height of thread at mean diameter, t = 3.5	mm
24	safe bearing pressure, P_b	kg/mm^2
25	polar section modulus, Z	mm^3
26	Design shear stress, τ	kg/cm^2

Total load on lead screw = Weight of boom + Weight of carriage + payload + weight of dust collection system.

= 100+ 600 + 600

= 2200 kg

≈2500 kg

Material for the lead screw is C-45(Hardened & tampered steel). Properties of material are given in table 2.

Table 2 Material property of lead screw

Sr. No.	Description	Value	Unit
1	Yield Strength	387.3	Mpa
2	Shear stress	157.9	Mpa
3	Young Modulus	210	Gpa
4	Ultimate Tensile stress	650	Mpa
5	Bending Stress	232.24	Mpa
6	Poisson ratio	0.29	
7	Hardness	229	BHN

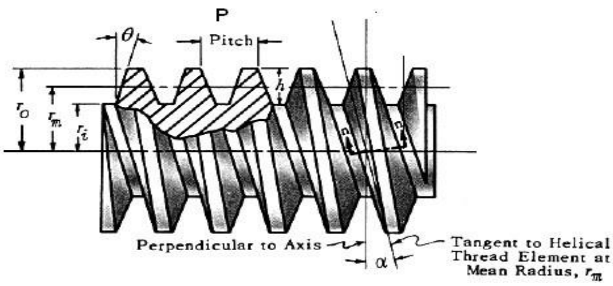


Figure 14.Cross section of lead screw [15]

lead screw will be subjected to tension loading due to load of carriage assembly and boom weight. The lead screw core cross section area must sustain that tension load.

$$\sigma_t = \frac{w}{A_c} \tag{23}$$

$A_c = 107.64\, mm^2$

But, Diameter of lead screw should be more than design cross section diameter of lead screw. Diameter of selected lead screw is 44 mm.

P = 7 mm

D_c = 36.5 mm

D_m= 40.25 mm

Based on core diameter of lead screw core area

$$A_c = \frac{{d_c}^2 * \pi}{4} \tag{24}$$

Helix angle of screw can be found from equation

$$\alpha = tan^{-1} \frac{p}{D_m * \pi} \tag{25}$$

Friction angle can be found from equation

$$\varphi = tan^{-1} \mu \tag{26}$$

Torque required to rotate the lead screw:

Lead screw is subjected to tensile loading of carriage assembly and boom weight with grinding head on the end of the boom.

P = Weight of boom + Weight of carriage + payload + weight of dust collection system - (60% of total weight/Counter weight)

= 1000 + 600 + 600 + 100 - (0.6*2500)

≈ 1000 kg

Required Torque to rotate the lead screw.

$T = 3820\ kgmm = 3.82\ kgmm$[21]

Selection of ball screw:

Motion is achieved by ball screw. Only guide ways will be subjected to load, ball screw will not be subjected to load but for more FOS, considering load acting on ball screw vertically downward equal to weight of head assemblies.[5]

P= 700 kg= 6860 kgf

Consider, L=1 million revolution,

$$L = \left(\frac{c}{p}\right)^3 \quad (27)$$

P=6860 kgf

From hiwin catalogue 50-10K5 is selected having dynamic capacity C =7050 kgf. [22]

preload calculation:

$$P = \frac{F_{bm}}{2.8} = 2450\ kgf \quad (28)$$

$$K_p = \frac{0.05}{\sqrt{\frac{10}{50*\pi}}} = 0.198 \quad (29)$$

$$Loaded\ torque\ (T_d)=\frac{K_p*P*l}{2\pi}= 7727.09\ Nmm \quad (30)$$

$$Drive\ torque\ (T_a motor\ drive\ torque\ (T_a)=\frac{F_b*l}{2\pi n_1} = 12131.14\ Nmm \quad (31)$$

T = $T_d + T_a = 19858.23\ Nmm = 19.85\ Nm$

Motor selection torque > 1.1 Nm

Life of ball screw for selected ball screw,

$$L = \left(\frac{c}{p}\right)^3 = 1.085\ million\ revolution$$

Compression Spring to compensate weight of head:

For grinding process, grinding pressure is acted on the grinding surface. Grinding pressure should be 10-20 kg as per the earlier calculation of grinding pressure. But grinding head has a weight of 300-400 kg which is too high for grinding process. So, excessive weight must be compensated by external arrangement. For compensation of excessive weight of grinding head, compression spring is the best option. Weight of head will be compensated by spring force which should be slightly more than weight of grinding head. It is also good for safety reason.

Material of spring is oil tampered wire. Material property of material is t = 420

Mpa , G = 80 kN=mm2 ; E = 210 kN=mm2

Let spring index, C = 4

W= 200 KG = 1800-2000 n=N

For finding wire diameter, d

$$Maximum\ stress\ in\ spring\ wire,\ \tau = \frac{K8WC}{\pi d^2} \quad (32)$$

$$K = wahl's\ stress\ factor = \frac{(4C-1)}{(4C-4)} + \frac{0.615}{C} = 1.40\ W \quad (33)$$

d = 8.24 mm , choose as per standard dimension.

Design of column and boom:

Requirements and Design considerations of Column boom arrangement:

Boom will be moved horizontally and it will be moved vertically with the carriage assembly. Amount of displacement of column in horizontal direction on column and amount of vertical displacement of carriage assembly on column should be decided. As per required movements of column and boom, length of column and boom can be decided.

Consider following data for the design of column boom, horizontal motion of boom = 1500 mm

Vertical movement of carriage assembly with boom on column = 3500 mm

rotation of column about base = 360

allowable deflection in boom = 6-8 mm

grinding arrangement will be mounted on the end of boom. So, there will be some deflection in boom due to weight of grinding arrangement.

approximate weights of grinding arrangement attached at the end of boom: Weight of grinding head : 350 kg

Grinding head rotation device :100 kg Horizontal guideways assembly: 200 kg total weight = 750 kg

During design calculation, factor of safety will be added on Loads for safe design. Specifications of column boom arrangement:

Table 3 Specifications of column and boom arrangement

Sr. No.	Description	Value	Unit
1	Vertical movement of column	3500	mm
2	Guide way on column	Trapezoidal	
3	Vertical feed drive	Lead screw	
4	Vertical feed rate	50-100	mm/min

5	boom horizontal stroke	1500	mm
6	boom guide way type	Trapezoidal	
7	Horizontal feed type	guideways	
8	Horizontal feed rate	5-100	mm/min
9	rotation of column on base	360	

Beam is important and critical part of grinding arrangement. Grinding arrangement will be mounted at the end of beam with turning mechanism and horizontal guide. Beam will be moved in horizontal direction with the help of rack and pinion. Beam is allowed to move in horizontal direction with the help of rack and pinion so that all motion of beam can be restricted. So beam will be acted like cantilever beam at one end fixed. Cantilever beam will be subjected to its own weight and weight of grinding head. For safety, weight will be considered in the calculation with the factor of safety.

For safety reason, take approximate twice load of head at the end of beam.

Point load at the end of boom, W= 350 kg

Uniformly distributed load, w = 0.15 kg/mm Weight of boom = 850 kg.

Total length of boom = stroke length + center distance + 1000

= 2500 + 1000 + 200

= 3700 mm

Deflection in boom:

Deflection in boom due to loads = deflection because to self-weight of boom + deflection because to point load

permissible deflection is 6 mm.

$$6 = \frac{wl^4}{8EI} + \frac{wl^3}{3EI} \qquad (34)$$

$$I = 26.30 * 10^6 mm^4$$

Deflection:

$$\sigma = \frac{0.15 * 2500^4}{8 * 2.1 * 10^4 * 26.30 * 10^4} + \frac{350 * 2500^3}{3 * 2.1 * 10^4 * 26.30 * 10^6}$$

$$\sigma = 4.626\ mm$$

Conceptualization 3D model

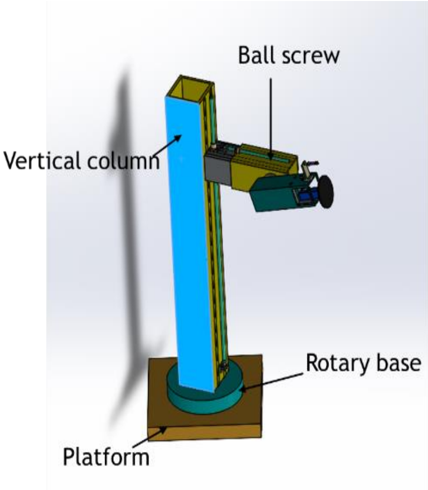
Design Process:

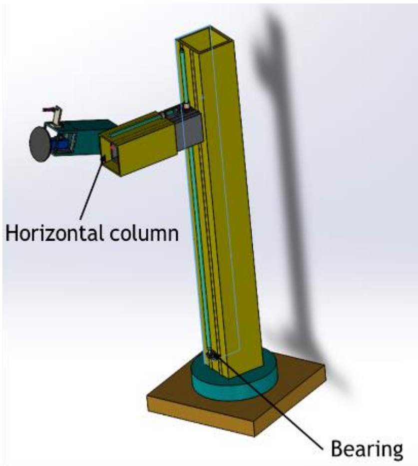
Step 1: Development of scheme

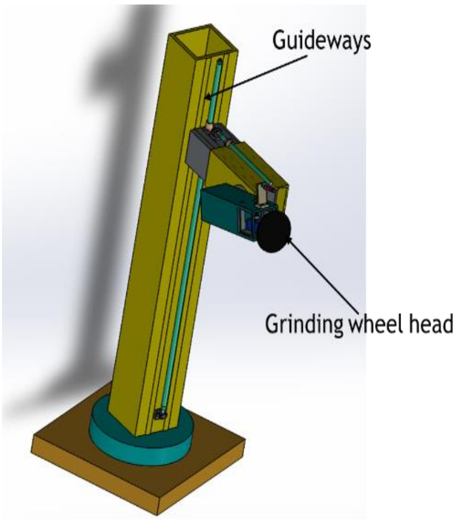
Design scheme for particular purpose or need, reflect the ideas and logic used to prepare certain design which is going to be made.

Step 2: 3d Solid modelling

Once the scheme will be finalized, each part with assumed dimensions is modelled and assemble. The modelling is done on CAD software SOLID EDGE 22.







Chapter 4

Modal and Random Vibrational Analysis of Grinding Machine Structure

Boom can be considered as cantilever beam at one end fixed. Boom has load on
200 N at the free end of beam.
Loading condition, deflection and induced stress of boom with the help of skyciv software.

4.1 SFD, BMD AND DISPLACEMENT:

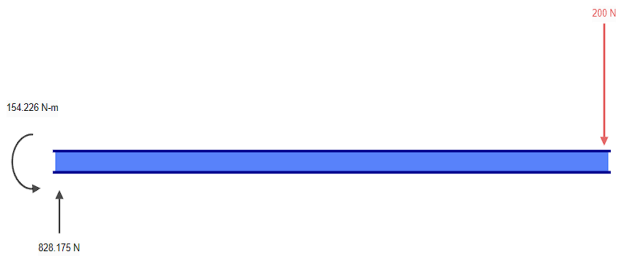


Figure 15 loading condition in skyciv software

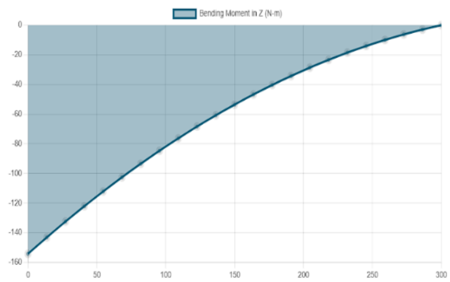


Figure 16 bending moment diagram

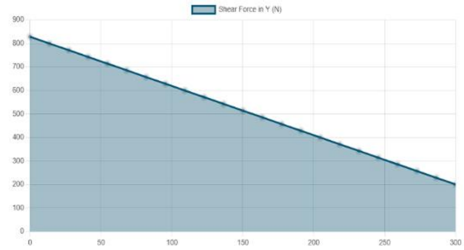


Figure 17 shear force diagram

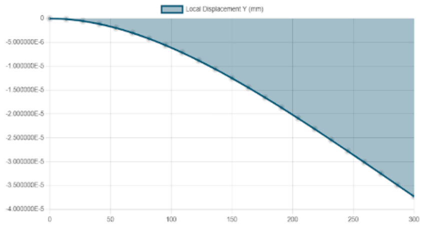


Figure 18 displacement diagram

Boom can be considered as cantilever beam at one end fixed. Total length of boom is around 4 m. Boom has load on 1500 N at the free end of beam and bending moment are also included 500 Nm at the end of the boom.

Loading condition, deflection and induced stress of boom with the help of skyciv software.

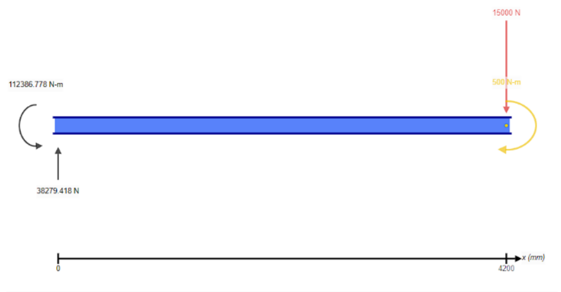


Figure 19 loading condition in skyciv software

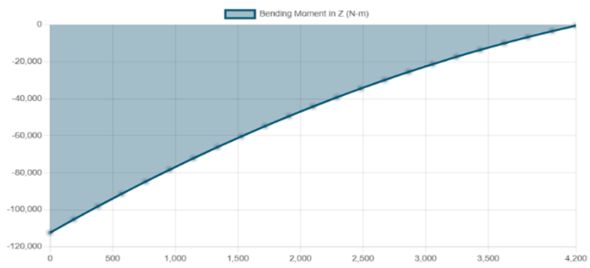


Figure 20 bending diagram

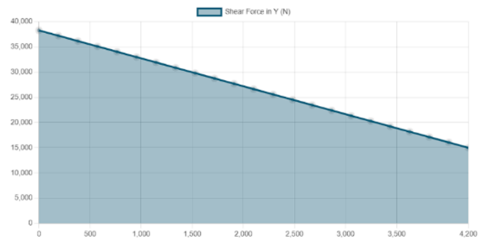


Figure 21 shear force diagram

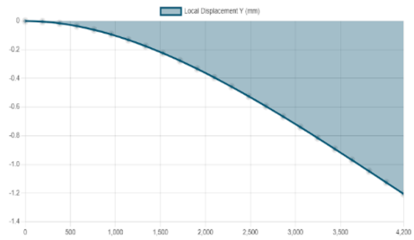


Figure 22 displacement diagram

4.2 STATIC ANALYSIS IN ANSYS:

Theoretical deflection of boom is found out in previous section, analysis in software is carried out. Result of analysis is given below. Grinding is mounted on this structure. Overall load is 1500 kg in downward direction. Analysis software is Ansys and mesh is 0.293m 3D tetrahedral and fixed boundary condition applied at end of the structure.

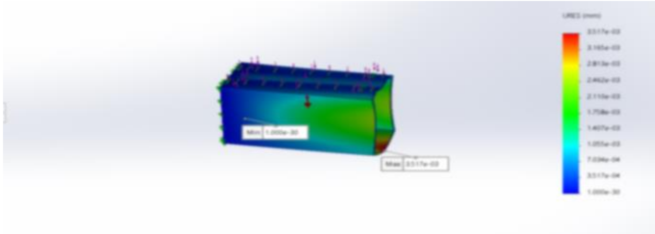


Figure 23 STATIC DISPLACEMENT (HORIZONTAL BEAM)

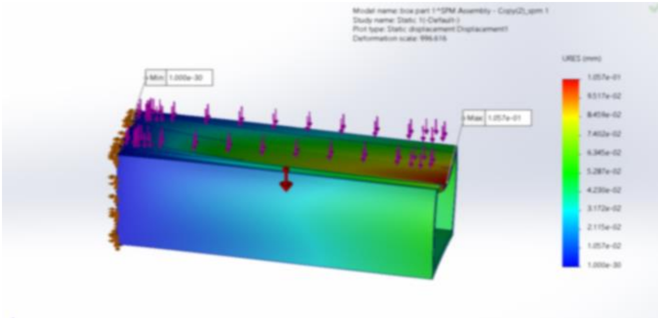


Figure 24 STATIC DISPLACEMENT

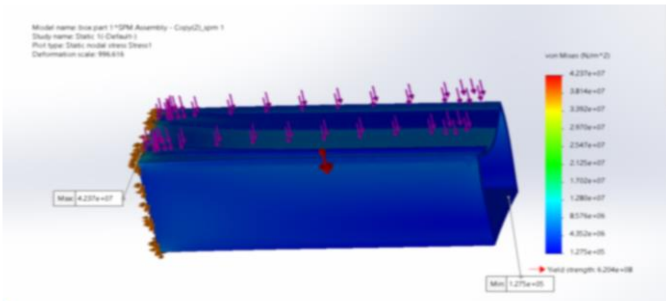


Figure 25 VON MISES STRESS

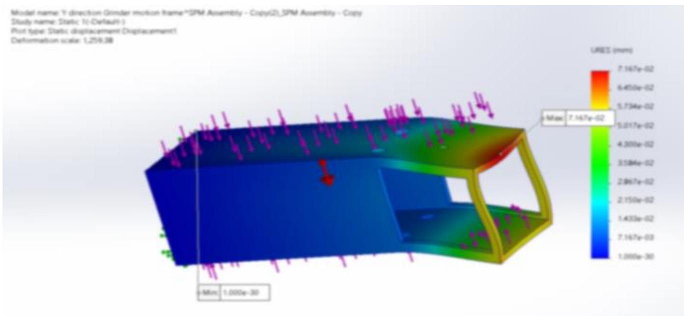


Figure 26 DISPLACEMENT OF GRINDING HEAD ARRANGMENT

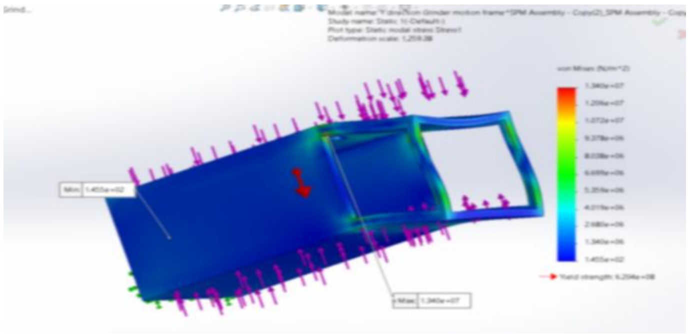


Figure 27 VON MISES STRESS OF GRINDING HEAD ARRANGMENT

4.3 MODAL ANALYSIS:

Modal Analysis calculates natural frequency and mode shapes of the structure. Participation factor shows the most prominent modes in a certain direction that will be excited by forces in that direction. Effective mass can be useful for confirming that enough modes have been extracted for further analysis.

Modal Analysis is performed using workbench ANSYS software package. The mode superposition method is used for determining the natural frequency and mode shape. After that, we got the natural frequency and each natural frequency have own mode shapes. This mode shapes are imposed in random vibration dynamic for determining the dynamic response of the structure. Refer below mode shapes for FEA plots.

Finding a structure's inherent dynamics response in the form of natural frequencies, damping factors and mode shapes is the process of model analysis. To create a mathematical model for its dynamic behaviour response, numerous parameters can be used. We refer to this mathematical model as the system's model for the analytical solution of the partial differential equation of a continuous system, Frequency and position physically illustrate the dynamic behaviour of any system. The foundation of model analysis is the idea that a linear time invariant dynamic system's vibration response may be represented as the linear combination of a group of straightforward harmonic motions known as the natural modes of vibrations.[31]

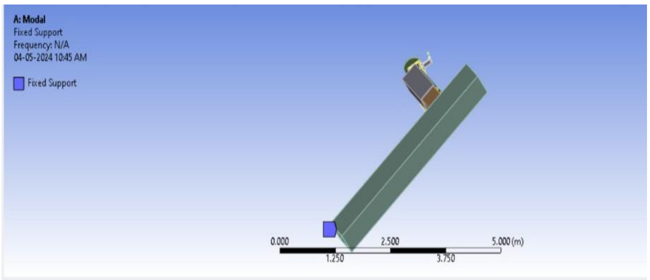


Figure 28 FIXED SUPPORT

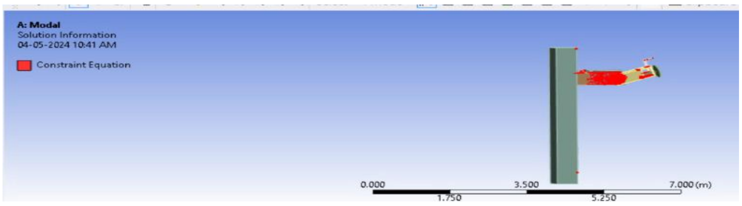


Figure 29 CONSTRAINT

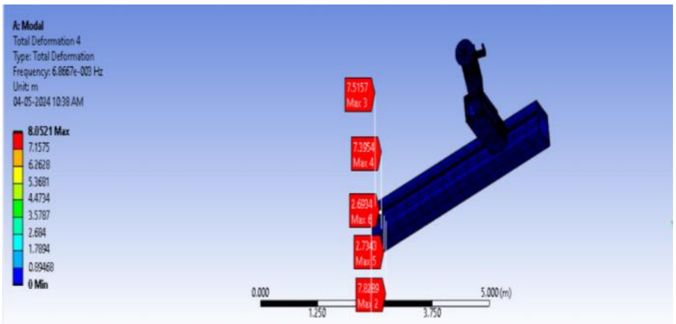


Figure 30 TOTAL DEFORMATION (1)

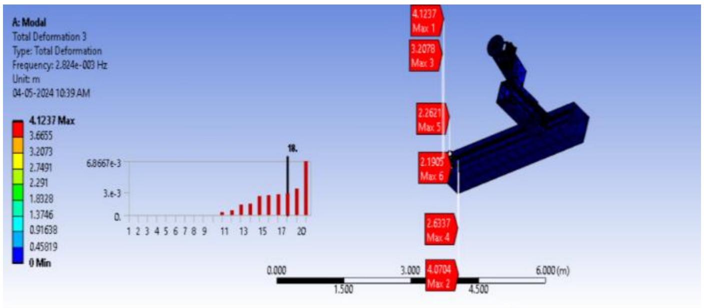


Figure 31 TOTAL DEFORMATION (2)

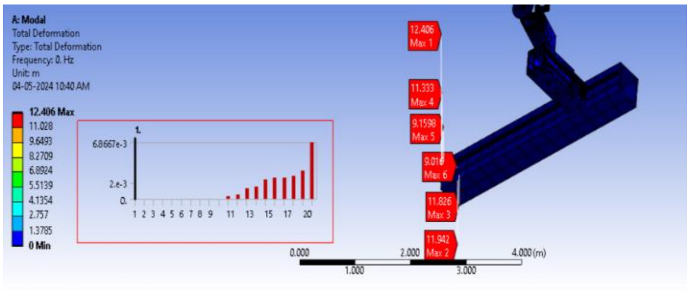


Figure 32 TOTAL DEFORMATION (3)

Finding a structure's inherent dynamics response in the form of natural frequencies, damping factors and mode shapes is the process of model analysis. To create a mathematical model for its dynamic behaviour response, numerous parameters can be used. We refer to this mathematical model as the system's model for the analytical solution of the partial differential equation of a continuous system, Frequency and position physically illustrate the dynamic behaviour of any system. The foundation of model analysis is the idea that a linear time invariant dynamic system's vibration response may be represented as the linear combination of a group of straightforward harmonic motions known as the natural modes of vibrations.[31]

Table 4 Analytical result of Natural Frequency

MODE	Frequency (Hz)	MODE	Frequency (HZ)
1	0	11	3.554e-004
2	0	12	5.703e-004
3	0	13	1.291e-003
4	0	14	1.484e-003
5	0	15	2.388e-003
6	0	16	2.530e-003
7	0	17	2.602e-003

8	0	18	2.824e-003
9	0	19	3.402e-003
10	0	20	6.866e-003

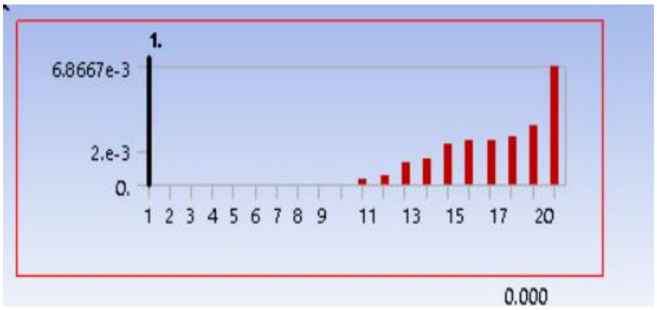


Figure 33 Graph of Mode Shape Vs Natural Frequency

4.4 RANDOM VIBRATION ANALYSIS:

Random vibration follows the modal analysis. Modal analysis is essential for performing the dynamic analysis. Without modal analysis we cannot find the any types of the dynamic responses of the structure.

The structure response under random loading is defined through the application of random vibration analysis. The power spectral density (PSD) spectrum used by ANSYS to analyse the load input's unpredictable vibration. As a type of probability static technique, Power spectral density is the root means square value of random variables, which includes information on frequency and energy of random vibrations. Powers spectrum can take many different forms such as, force power spectral density, acceleration, velocity or displacement.

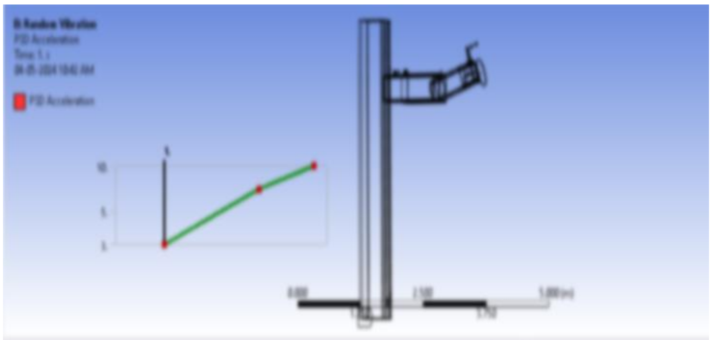


Figure 34 PSD ACCELERATION

The Figure 37 shows the PSD Acceleration and Time graph about the specific ANSYS analysis. The graph most likely depicts the power spectral density of the pole's acceleration as a function of Height, though given the caption PSD acceleration on the y-axis. the amount of vibration energy present in various frequencies measured by the PSD. At the specific frequency more vibration energy is Indicated by higher value on Y-axis.

Table 5 At different Frequency (Hz) value of Acceleration

Frequency (Hz)	Acceleration[(m/s^2)^2/Hz)]
1	3
2	7
3	10

The Table 5 shows the PSD of the pole's Acceleration, that given the designation PSD Acceleration on the Y-axis. The result shows the Frequency (Hz) vs Acceleration [(M^2)^2/Hz)] At frequency 1,2 and 3 respectively 3,7 and 10.

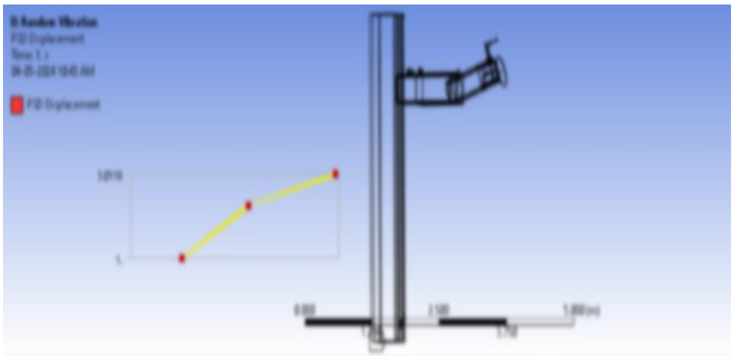


Figure 35 PSD Displacement

Table 6 At different frequency value of Displacement

Frequency (Hz)	Displacement[(m^2)/HZ]
1.e-004	1
2.e-003	2
0.1	3

The Figure 38 shows the PSD of the pole's displacement, that given the designation PSD Displacement on the Y-axis. The result shows the Frequency (Hz) vs Displacement[(M^2/Hz)] At frequency 1.e-004,2.e-003 and 0.1 respectively 1,2 and 3.

Chapter 5

Conclusions

The requirements of grinding such as weld edge preparation, Surface finishing and back gouging or chip back can be done by grinding process and the proposed material removal arrangement is suitable for the same. The grinding machine is designed having four degrees of freedom. Those all motions are sufficient for achieve all grinding points on T-joint. Machine components are mounted on structural components which are analysed in analysis software Ansys.

- Maximum Static displacement in small horizontal beam, outer big horizontal beam and grinding head at respectively, 3.51×10^{-3} mm,0.01057 mm, 0.0716 mm.
- Maximum Von misses stress in horizontal beam and grinding head arrangement is respectively 4.23×10^{7} N/m^2 and 1.34×10^{7} N/m^2.
- Modal Analysis in at 0 Hz frequency maximum displacement occur at bearing around 0.012 m. After that increasing frequency step by step displacement are decreasing gradually.
- Random vibration Analysis in Acceleration at 1 Hz,2 Hz,3 Hz frequency respectively, 3,7 and 10 [(m/s^2)^2/Hz] at this point maximum displacement occur at X-direction with 0.011 m.

FUTURE SCOPE:

Development of the grinding machine structure and it is operated by an automatic as per requirements and using IOT based platform for real time analysis and result.

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