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Automation of Stone Feeding on T8 Honing Machine

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Abstract: Honing is an abrasive machining process that produces a precision surface on work piece by scrubbing an abrasive stone against it along a controlled path. Honing uses a honing stone or a hone, to achieve a precision surface. The hone is composed of abrasive grains that are bound together with an adhesive. It is used for surface finishing outer surface of the inner race and the inner surface of the outer race of taper roller bearings. It is bound to wear and tear. The honing stone is then manually adjusted so that the abrasive surface comes in contact with the material to be machined. Hence, the machine has to be stopped and the operator needs to adjust the stone accordingly. The stopping, adjusting and restarting of the machine increases the idle time of the machine. Therefore, it is necessary to automate this process. We will be using a position based process for the movement of the honing stone after the abrasive material is eroded by 2mm. This will decrease the idle time and increase the productivity.

Keywords: Honing, Bearings, Wear of stone, Automation.

I. INTRODUCTION

Honing is a cutting process where multi-edge tools coated with particles with continuous surface contact between the tool and work piece are used to optimize the dimension, form and surface of pre-machined work pieces. Between tool and work piece a change in direction of the longitudinal movement takes place. The finished surfaces are characterized by a cross-hatch pattern on the surface.
The work process with honing is a combination of stroke and rotation movement of an expandable honing tool with inserted honing stones or diamond sticks. The result is the surface structure with cross-hatch pattern generated by the honing process. The timing of the honing is defined by quick cutting of the peaks of the pre-machined bore surface. This rapidly achieves a smoothing of the surface.

Applications: Finishing of cylinders for internal combustion engines, air bearing spindles and gears. There are many types of hones but all consist of one or more abrasive stones that are held under pressure against the surface they are working on.

SKF India has most important operation of Honing to be performed on internal side of outer race of bearing. After performing grinding on bearing material the honing gives perfect finishing to surface.

As rotation on roller or ball of bearing is necessary to be very smooth & very easy to work with maximum efficiency. Bearing working principle depends on very smooth rolling of supporting rollers or balls. Honing allows to super finish the surface to make it very easy for motion with slight lubrication over it. There are different techniques used for honing operation like Longitudinal Stroke Honing, Short stroke honing, Centreless plunge honing etc.
Honing uses a special tool, called a honing stone or a hone, to achieve a precision surface. The hone is composed of abrasive grains that are bound together with an adhesive. Generally, honing grains are irregularly shaped and about 10 to 50 micrometres in diameter (300 to 1,500 mesh grit). Smaller grain sizes produce a smoother surface on the workpiece.

A honing stone is similar to a grinding wheel in many ways, but honing stones are usually more friable so that they conform to the shape of the work piece as they wear in. To counteract their friability, honing stones may be treated with wax or sulphur to improve life; wax is usually preferred for environmental reasons.

II. PROBLEM STATEMENT

Installation of automatic stone feed mechanism in a T8 channel FTC honing machine.
In SKF honing is used for surface finishing operations of taper roller bearings. A silicon carbide honing stone is used. The stone wears out after machining of around 350 components. The stone has to be moved forward by required distance. Existing tool feeding system is a manual system, which terminates when stone wears out and to manually feed the stone, human efforts as well as time is required. It increases cycle time per product. It affects dimensional accuracy and quality of the product and also reduces the productivity.

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The system requires automation to get maximum efficiency while working without interruption due stone wear. To develop automatic clamping & declamping unit which can hold honing stone with desire pressure. There is need to develop a proper holding arrangement which can fit in specified area, which is less than internal diameter of outer race of ring on which operation is to be performed.

III OBJECTIVES

1. To design and develop stone feeding system.
2. To validate it by its practical implementation on actually machining operation.
3. To check the differences between manual and automatic stone feeding machine so as to overcome loses.
4. To increase the number of components produced per batch.

IV SCOPE

Our scope during this project work was limited to mechanical system design.
1. To develop a mechanism to fulfill above mentioned objectives.
2. To design a mechanism without affecting the quality of honing.
Any work on PLC programming is within sponsor's scope.

V. METHODOLOGY

Following are the methodological steps that are taken to arrive at the desired results during this project.
1. Literature survey on existing scenario.
2. Problem definition.
3. Selection and finalization of mechanism.
4. Design and analysis of mechanism.
5. Fabrication of system.
6. Implementation of system.
7. Benchmarking of system.

VI SELECTION OF MECHANISM

After studying about various tool wear compensation techniques and building a basic understanding of the problems related to them, some mechanism are proposed to automate the existing feeding system. From past experience a wear of 2 mm was considered acceptable before the surface finish of bearing race started degrading. The two major steps to be done during this automation are
1. Detection of 2 mm tool wear.
2. Mechanism for compensation of this 2 mm tool wear.
This chapter describes in brief, all the proposed mechanisms along with their advantages and limitations. Finally, the approved mechanism is explained along with its design steps.
For detection of tool wear inductive proximity sensor was finalised as it had all the properties and application which are required to carry out the operation.
For the mechanism of compensation of tool hydraulic system is being finalised its design aspects are mentioned below.

A. Hydraulic system
For designing a hydraulic system the very first step is to prepare a basic logical circuit. To prepare this circuit a sequence of operations to be performed is required. Following is the practical sequence of operations to be followed to get the desired motion of tool.

- To sense the tool wear of about 2mm, this is done by inductive sensor.
- This sensor activates the piston cylinder arrangement and the piston moves forward such that it touches the tool. This is sensed by another inductive sensor.
- The sensor activates the clamping/declamping mechanism and finally declamps the tool.
- After the tool is declamped the feeding mechanism pushes the tool by 2mm.
- After the tool is feed by 2mm the tool gets clamped.

Based on this sequence a hydraulic circuit is proposed as shown below.

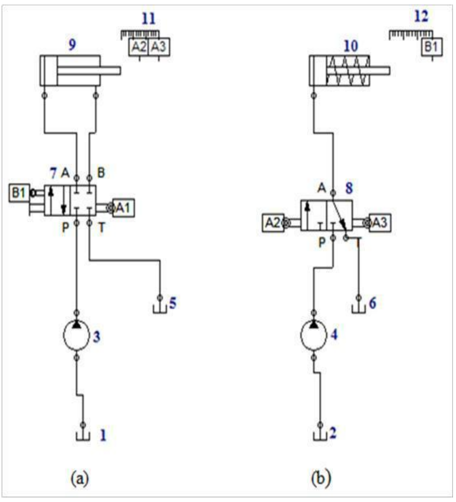

Fig 1 Proposed Hydraulic Circuit; (a) feeding circuit; (b) clamping circuit

B Components of Hydraulic circuit are as follows:
- 1, 2, 5, 6- Tank.
- 3, 4- Fixed displacement pump.
- 7- 4/2 Direction Control Valve.
- 8- 3/2 Direction Control Valve.
- 9- Double action cylinder.
- 10- Single acting cylinder (spring retraction)
- 11, 12- Displacement rule.
- A1, A2, A3, B1, - Limit switches or Sensors.

When the honing stone tool wears about by 2mm, the inductive sensor gets activated. This activation of sensor is linked with direction control valve [7] which allows the flow of fluid from tank to double acting cylinder [9]. Now

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the piston moves forward until it touches the tool. When it touches the tool, sensor A1 and A2 activates. Sensor A1 then changes the spool position of direction control valve [7] and sensor A2 changes the spool position of direction control valve [8]. Due to the change in position of direction control valve [7] the cylinder gets locked into it current position. Due to the change in position of dcv [8] the single acting spring loaded cylinder moves forward and de-clamps the tool. By the time it de-clamps sensor B1 gets ON. This sensor B1 changes the position of DCV [7], due to which the cylinder [9] moves forward from is present position. The piston of cylinder [9] now moves the tool by 2mm. This movement of tool by 2mm is sensed by A3 sensor. Sensor A3 then sends a signal due to which DCV [8] changes the position. Now the piston of cylinder [10] retracts due to opposite force of spring. Which means the tool has being clamped again and the honing cycle can be continued.

C. Design of Hydraulic System
The characteristics of all the components and their functioning should be considered while designing the system. Other important aspects which should be considered in design are:

- Safety of operation
- Performance of desired function
- Efficiency of operation

The factors along with the task have to be considered with a view to arriving at the best possible design. Following are the assumptions made while designing the hydraulic circuit.

- The maximum force on cylinder piston is about 9.80kN.
- The maximum stroke of cylinder is about 300mm.
- The maximum velocity of piston is to be about 0.0667.
- The working pressure, maximum is about 50bar.

D. Selection of hydraulic actuator:
The maximum working pressure= 50bar
Since P= F/A.

$$50*10^5 = \frac{9.8*10^3}{\frac{\pi}{4}*d^2}$$

d = 49.96mm
Hence rod diameter = 50mm
From the table select rod diameter = 50mm.
And bore diameter corresponding to 50mm is 100mm.
So A5 model of cylinder is selected

E. Check for maximum pressure:
Since total stroke of cylinder = 300mm
Full bore area = $\pi/4$ * D² = $7.85*10^{-3}$
Where D=100mm.
And annulus area = $\pi/4$ * (D²- d²) = $5.8875*10^{-3} m^2$
So the maximum pressure = load/area

$$= \frac{9.8x10^3}{7.85\times10^{-3}}$$

= 12.738 bar

Hence the selected cylinder is safe.

F. Maximum flow rate:
The maximum velocity assumed is 0.06667 m/s.
Therefore discharge Q = Area x velocity.
$7.85*10^{-3} \times 0.06667$ = 31.42 lit/min

G. Selection of Direction control valve:
Maximum flow required in hydraulic circuit is 31.42 lit/min and maximum pressure is 12.738 bar. Hence the Direction control Valve D2 is selected from the table.

H. Selection of pump:
Maximum flow required in hydraulic circuit is 31.42 lit/min and maximum pressure is 12.738 bar hence pump must provide the required flow against the required pressure. From the table the P5 model of vane pump is selected because this satisfies our requirement.

I. Selection of reservoir:
Sizing of the reservoir from thumb rule formula is (3 to 4) x pump delivery/min.
= 3 x 31.42 = 94.26 liters.
Hence from the table the oil reservoir of model T2 is selected.

Table 1 designation and its capacity

Sr. No.	Name of component	Model	Flow capacity
1	Suction Strainer	S1	38lpm
2	DCV	D2	38lpm
3	Vane Pump	P5	At 35bar, 37.5lpm
4	Cylinder	A5	Bore = 100mm
			rod = 50mm
5	Oil reservoir	T2	Capacity =100 litres

J. Limitations of using hydraulic system
The pump runs continuously, and if the accumulator and the hydraulic cylinders are not in need of the fluid, a valve between the pump and accumulator dumps the excess fluid back into the reservoir.

So the energy consumption of the system is always on full throttle as soon as the pump is turned on. Any thoughts of turning the pump on only when one needs the pressurized fluids are dashed by the requirements of the systems.

The fluid needs to be warmed up and any bubbles removed. Bubbles of air are compressible, and would compromise the overall performance. This has been one of the limitations of hydraulic systems.

H. Ball Screw Actuator

The ball screw drive is an assembly that converts rotary motion to linear motion (vice versa). It consists of a ball screw and a ball nut packaged as an assembly with recirculating ball bearings. The interface between the ball screw and the nut is made by ball bearings which roll in matching ball forms. With rolling elements, the ball screw drive has a very low friction coefficient and is typically greater than 90% efficient. The forces transmitted are distributed over a large no of ball bearings, giving a low relative load per ball comparatively.

J. Selection of Ball Screw Actuator

Selection of electric cylinder is based on diameter of spindle and required stroke length. Assuming the required stroke length to be approximately 200mm. Standard dimensions of the honing tool is 13.4x12x62 mm.

- Therefore, effective cross-section area is 13.4 x12 mm².
- To find the max. diameter of spindle of the actuator,

$$\frac{\pi}{4} d^2 = 13.4 \times 12$$

- Therefore, d=14.31mm (approx. 15mm). From the standard catalogue of cylinders (FESTO) available we select DNCE-32-200-BS-"10"P-Q [21].

Table 2 Designation of Selected Ball Screw Actuator

Basic configuration feature	Value
Function	DNCE Electrical cylinder
Size	32mm
Working stroke	200mm
Variable stroke	200mm
Drive type	BS Ball screw spindle
Secured against rotation	Q non rotating piston rod
Spindle diameter	10mm
Piston rod thread	M10*1.25
Motor type	Stepper
Max speed	0.5m/s
Max. drive torque	0.8 Nm
Weight	1.5kg

Table 3 Specifications of Selected Ball Screw

DNCE	Company's product code
32	Size
200	Stroke length
BS	Ball screw
"10"	Spindle diameter

K. Selection of Stepper Motor:

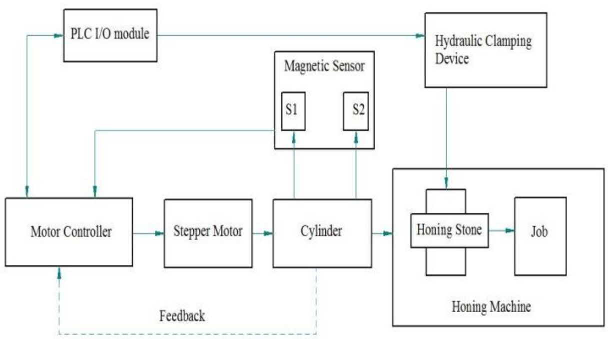
From specifications of electric cylinder maximum drive torque is found to be 0.8 Nm. This criterion is considered while selection of stepper motor for ball screw actuator. Based on this maximum torque limit, stepper EMMS-ST-42-S-SE-G2 is selected. [21]

Table 4 Specifications of Selected Stepper Motor.

Feature	Values
Holding torque	0.5 Nm
Max. rotational speed	1740 rpm
Stepper angle	1.8±5%
Nominal Voltage	48 V DC
Nominal Current	1.8 A
Weight	0.45g

After selecting the electric actuator and stepper motor, it is needed to select a compatible motor controller. From standard selection catalogue of FESTO, motor and controllers, CMMO-ST is selected. CMMO-ST is a closed-loop servo controller for stepper motors, equipped with various functions. It includes low heat development, monitored safe positions and smooth motor running curve. This sets the stepper motor controller CMMO-ST apart from conventional controllers of this type. Alternatively, the CMMO-ST can also function as a low-cost open-loop system with stepper motors without encoder. The extensive range of functions and the optimum price/performance ratio provides further advantages.

VII BLOCK DIAGRAM OF HONING MACHINE STONE FEEDING MECHANISM



VIII DESIGN OF SUPPORT STRUCTURE FOR ACTUATOR

A. Analysis of the Supporting Structure using ANSYS

Static structural analysis of the designed supporting structure for electric actuator is done using ANSYS Workbench.

Following are the steps followed during the analysis.

Step 1: Meshing

The assembly of supporting structure is meshed using tetrahedrons with element size of 5 mm.

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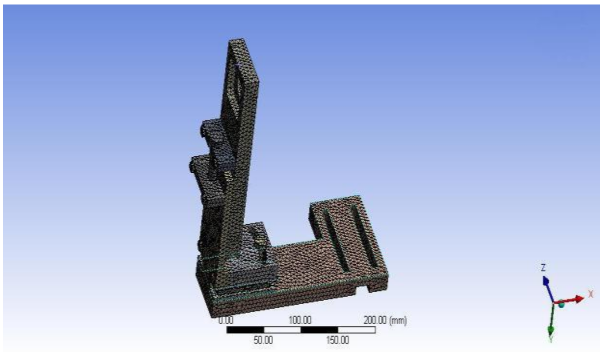

Fig 2 Meshing Support Structure.

Step 2: Restricting DOF
A fixed support is applied to the lower face of the base plate as shown.

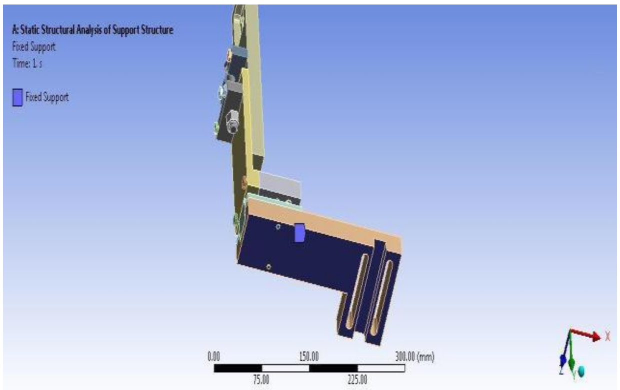

Fig 3 Fixed Support.

Step 3: Applying Moment
It is assumed that the combined weight (20 N) of electric actuator and stepper motor is concentrated at the end of electric actuator which is located at a distance of 150 mm from the holding column. Hence a moment of 3000 N-mm is applied as shown.

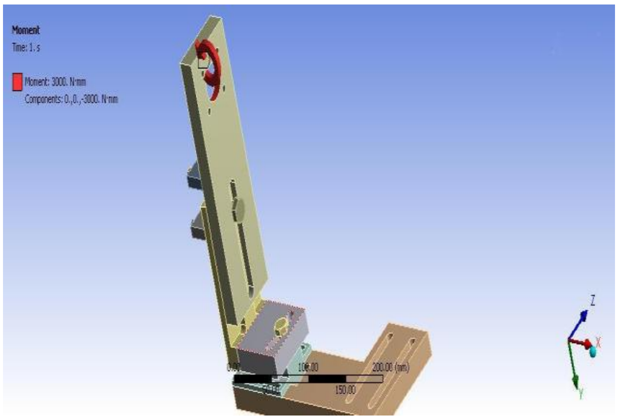

Fig 4 Applying Force

Step 4: Applying Force
A force of 20 N is applied on the bolt holes and actuator holding hole as shown in following figure.

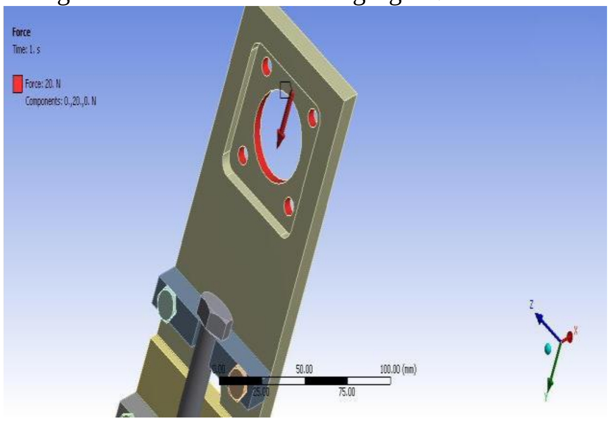

Fig 5 Applying Force.

Step 5: Applying Bolt Pre-tension
According to standards for low carbon steels (45C8) min proof strength is 225 MPa [22]. The pre-tension on bolt will be 2 kN.

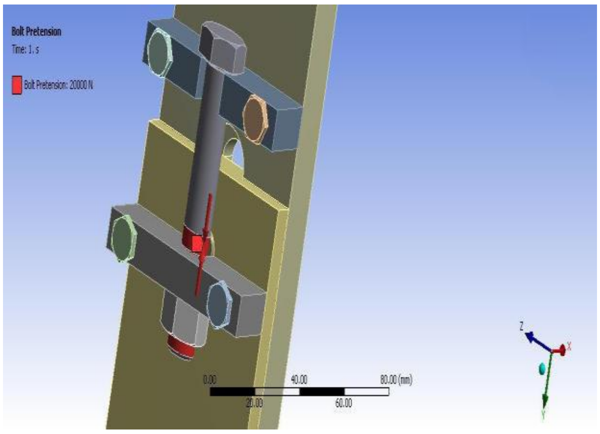

Fig 6 Bolt Pre-tensioning

Step 6: Solution
Following are the results obtained after solving.

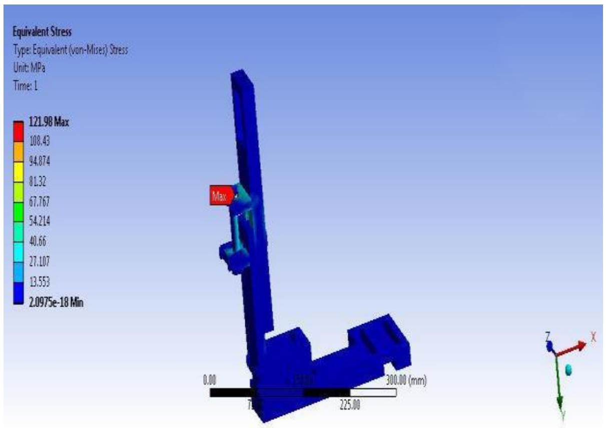

Fig 7 Equivalent Stress.

Material is taken as C45 and the yield strength of mild steel is taken as 380Mpa. Considering a factor of safety of

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2 we will get the allowable stress which will be 380/2=190MPa. The equivalent stress obtained was less than the allowable stress. Hence the design is safe.

IX. DESIGNING

A. Design of Swivelling Arm

Fig 8- Image of swivelling arm

X. DESIGNING A HYDRAULIC CLAMP

A. Parameters to design Hydraulic Clamping Unit

1. The stone being feed to surface of bearing is pressure controlled.
2. The honing pressure control system requires stone to apply pressure of 2 bar on surface of Bearing being honed.
3. To maintain pressure of 2 bar at tip of honing stone, Clamping unit must put more than 2 bar pressure on stone holder so that it can sustain in honing operation.
4. Hydraulic clamp must hold the stone even after the declamping the stone for moving forward.
5. This states that hydraulic system requires two different pressure at two different conditions, that is one while honing operation is being performed on race of bearing & another when stone is to be moved forward from clamp to match the honing requirement.
6. Two different pressure should be maintained by single clamp.

B. Proposed design for hydraulic clamp:

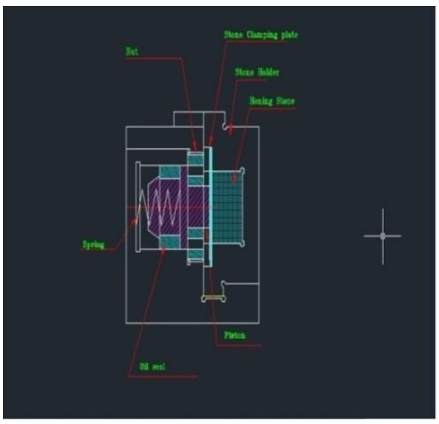

Fig 9 Front view of Hydraulic Clamp

C. Working of Proposed Design

1. Design Have Square clamping cavity when stone is to be fitted to be clamped.
2. A spring is fitted perpendicular to stone motion direction.
3. Spring applies force on plunger which pushes stone on another side to hold properly.
4. spring & plunger are sealed unit where hydraulic seal is provided.
5. From hydraulic seal the hydraulic oil can come in, same will not leak to stone or bearing.
6. Hydraulic oil too applies pressure on (pressure plate) clamping plate. Which pressure is real clamping pressure.

D. Calculations For Hydraulic Clamp

Calculating the strength of a clamping nut used in manually operating machine.

Material used EN8

Yield strength = 465N/mm^2

Maximum tensile stress = 700-850 N/mm^2

0.2% proof stress = 450 N/mm^2

Hardness = 201/255 Brinnel

Impact KCV = 28 joules

% of Carbon EN-8 = 0.36 - 0.44

1) $\sigma_t = \frac{Syt}{factor\ \ of\ safety}$

850 N/mm^2 = $\frac{465\ N/mm^2}{factor\ \ of\ safety}$

Factor of safety = 0.547

2) $\sigma_t = \frac{P\ (load)}{\frac{\pi}{4}dc^2}$

$850 = \frac{P}{\frac{\pi}{4}\times 8.773}$

P = 5856.753 N

3) Finding Pressure required to clamp the stone

Considering torque required 750 N-mm as it is applied by spanner and hand on nut head.

$T = \frac{W\ d\ m}{2}\left(\frac{\mu sec\ 30+tan\ 25}{1-\mu sec\ 30\ tan\ 25}\right)$

$750 = \frac{W\times 0.9\times 10}{2}\left(\frac{0.5\times 1.54+0.0436}{0.423-0.0436}\right)$

$750 = 4.5\ W\left(\frac{0.6206}{0.3794}\right)$

458.71 = 4.5 W

W = 261.58 N

W≈ 270 N

Hence designing Hydraulic clamp for minimum pressure of 270 N.

4.2.5 Calculations for Spring

d = 0.8

P = 50 N

δ = 12mm

Spring material : Cold drawn steel wire.

Permissible Shear stress

τ = 0.50 Sut = 975 N/mm²

[Sut = 1950 for Grade 2 for d = 0.8]

C = 5   D = 5

Number of active coils:

$\delta = \frac{8PD^3N}{Gd4}$ N = 7.99 = 8 coils.

Free Length of Spring:

$\delta = \frac{8PD^3N}{Gd^4}$ = 12mm

Total number of coils:

Assumed that spring has square and ground ends so the number of inactive coil is 2

Nt = N+2 = 8+2 = 10 coils

Solid length of spring:

Ntd = 10(0.8) = 8mm

Wahl factor :

$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$

K = 1.123

It is assumed that there will be gap of 1mm between consecutive coils when spring is subjected to maximum force.

Total number of coils is 10.

Total axial gap between coils= (10-1) = 9mm

Free length = solid length + total axial gap + δ

= 8 + 9+ 12 = 12m

Pitch of coil = $\frac{Free\ length}{(Nt-1)} = \frac{29}{(10-1)}$ = 3.22mm.

XI. EXPERIMENTAL VALIDATION

A. Stepper Motor Program Validation

Stepper motor EMMS-ST-42-S-SE-G2 was programmed using a software developed by FESTO, Festo Configuration Tool. Following figure shows the record table created using FCT.

Table 5 Record Table for Stepper Motor Validation

No.	Type	Target	Start condition	Velocity(mm/s)	Acceleration/ Deceleration(m/s2)
1	PA	140m	Ignore	100.00	1.000
2	FSL	10.0%	Delay	30.00	1.000
3	PRA	0.00 mm	Ignore	5.80	0.200
4	PRN	2.00 mm	Ignore	10.00	0.200
5	PA	0.00 mm	Ignore	100.00	0.200

PA: Positioning to absolute position.

FSL: Force Control –stroke limit active.

PRA: Positioning relative to actual position.

PRN: Positioning relative to nominal position.

The above program was validated step by step:

- After initialization of the program first record was run and the cycle was stopped. The stroke length was measured using vernier caliper.
- For second record the actuator moved forward until it sensed 10% back force due to the presence of tool and it came to rest.
- In third record, current position of actuator was set as home position by the controller.
- Now the controller moves the actuator and hence the tool by 2 mm from the new home position. This was validated by marking initial position and final position on the tool and measuring it by vernier caliper.
- The fifth record sends a signal to controller to retract the actuator to absolute home position.

XII IMPROVEMENT IN PRODUCTION

Table 6 Production and Downtime per Shift.

Parameter	Before	After
Production per shift	5000	5500
Machine Downtime per shift	45 min	25 min

Before implementation of new system the production per shift was 5000 bearing rings. Implementation of the new system has resulted in increase in production by 500 bearing rings per shift. 1 shift consists of 8 hr.

XIII CONCLUSION AND FUTURE SCOPE

In this project, earlier the mechanism used for compensating the tool wear was manual, but after implementing the proposed mechanism it was successfully automated. Various parameters were measured to examine the new system. There was a significant decrease in the surface roughness value. Before implementing the newly automated honing machine stone feeding mechanism the surface roughness of the inner race of bearing ring was 0.16 µm and now it is found out to be 0.14 µm.

By implementing the newly automated honing machine stone feeding mechanism the production of bearing rings was increased by 500 rings per shift. Earlier the production of bearing rings was 5000 rings per shift. This shows that the production has been increased by 10%. It can be concluded that the machine downtime per shift earlier was 45 minutes which has been decreased to 25 minutes. Thus the total downtime of honing machine per shift was reduced by 45%.

It can be seen that a wear of 2 mm in honing stone occurs approximately after honing 400 bearing rings. Thus, after every two shifts the operator will need to change the honing stone. This will result in machine downtime. If an automated mechanism is developed to replace the honing stone after it has been completely worn out, the machine downtime can further be reduced. Hence there is a future scope to automate the replacement mechanism of honing stone.

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