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Structural Design of a Painting Station for an Impeller Casing

M. Michael Jones[1], P. Sathyabalan[2], P. Anush[3]
[1] PG Student, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore
[2] Professor, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore
[3]Assistant Professor, Department of Mechatronics Engineering, Kumaraguru College of Technology, Coimbatore

Abstract: Blackening is done over the impeller casing to increase the durability of the pump. Advancement in technology has fostered the application of robots to overcome the shortage of labor in industries. Though industrial robots are capable of providing a smooth finish and uniform coating, the cost involved prohibits its application in small-scale industries. Hence a prototype is designed to automate painting the impeller casing of a centrifugal pump. The loads experienced by the support shafts are identified. The required geometry and design for a beam to support the nozzle at the required stiffness are determined. The required torque on the leadscrew to withstand the loads are determined. The loads experienced by the bearings are determined and suitable bearings are selected. 3D model of the prototype has been enabled in SOLIDWORKS. The critical structural components have been analyzed using ANSYS.
Keywords : Spray painting, Impeller Casing, Leadscrew design, Structural Analysis

I. INTRODUCTION

The centrifugal pump industry is a fast-growing industry. These pumps are exposed to rough handling and alternating weather conditions. Protective treatment over the impeller casing increases the durability of the pump. The impeller casing is cast and a uniform anti-rusting oxide coating is applied at the pre-treatment stage. The motor impeller and the casing are assembled and a final blackening process is done to attain smooth finish. Advancement in technology has fostered the application of robots to overcome the shortage of labor in industries. Though industrial robots are capable of providing a smooth finish and uniform coating, the cost involved prohibits its application in small-scale industries.

The idea of this project is to design and fabricate a low-cost CNC machine to paint the impeller casing, in order to bring automation in painting to more small-scale industries. To design the machine, the loads experienced in the machine while painting is identified so that the structures to be used in various parts of the machine can be determined. Initially, static loading conditions are considered ignoring dynamic loads. This estimate could be validated to vibrational modes if the structure is stiff enough to static displacements.

II. BASIC DESIGN AND FUNCTIONAL REQUIREMENTS

Customers are the end users of the machine. Therefore a set of requirements listed by the customers are described in this section.

A. The machine must be compact. This is to allow it to fit on a workbench easily.
B. To reduce the environmental hazard, the machine should be easily enclosable to prevent paint from spraying around.
C. The machine should be flexible to load and unload the parts. This is to reduce the lead time spent in manufacturing the pump.
D. The rates at which the nozzle is moving is important, as the time required to complete a job is to be set.
E. The driving screws should be free of paint so that motion of the nozzle is smooth.
F. To establish flexible manufacturing system, the machine should be able to handle varied sizes of the pump. To reach the goal, the machine should have the nozzle in one axis that is unobstructed, and the lift table set for the pump should be able to operate the load.
G. The precision of the operations should be 1mil (25μm). This is to ensure that only the intended portion of the pump is painted.
H. The machine should use standard components where possible and restrict the structure to common materials like steel and aluminium in order to reduce the cost.

III. CONCEPTUAL DESIGN

An initial design is to decide the actuation system to position the nozzle. This can be achieved using either a Gantry type or a Bridgeport type design. In Gantry type the nozzle can be mounted on a gantry that moves in the horizontal plane with a vertical degree of freedom. In Bridgeport design, the table can move in the x, y and z directions, the nozzle can be lowered and raised as well as rotated. Although gantry design is not flexible it can avoid the spillage of paint over the actuation system and it can be easily used for varied pump sizes as the load over the table changes with size. Therefore the Gantry design will be the suitable design for the machine.

The linear actuation of the nozzle along the X, Y and Z axes can be achieved using a rack and pinion, a belt drive or a leadscrew system. The rack and pinion actuation are not suitable because the driving motor will need to be geared down so that one turn of the motor does not cause too much linear movement, making the linear movement not very sensitive. This is the same for the belt driven system, where the pulley has to be geared down. Using leadscrew results in a significant speed reduction dependent on the pitch angle of the leadscrew. With the limitations discussed above and the requirement for workpiece size, a 3D model of the conceptual design shown in Figure 1 was developed in Solid works modelling software.

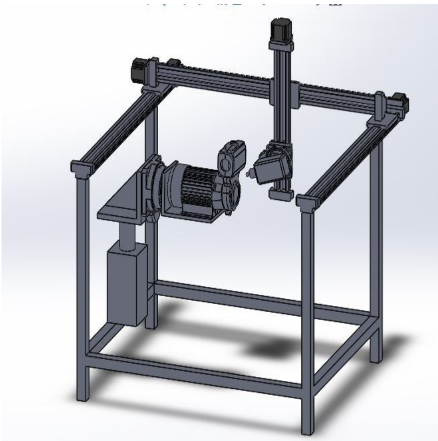

Fig. 1 3D Model of the Conceptual Design.

The axes of the machine would be actuated using leadscrews. Most linear slides consist of a leadscrew actuator in the middle with two shafts running parallel to provide support [5]. The lift table is provided with a pneumatic cylinder ensures for easy and safe loading and unloading. Answering following technical concerns will enable the design of the basic structure of the machine that could meet the functional requirements prescribed previously.

A. What are the loads experienced by the support shafts?
B. What is the required geometry and design for a beam to support the nozzle at the required stiffness?
C. What is the required torque on the leadscrew to withstand the loads applied to it? This question would help determine the torque of the motors required.
D. What are the loads experienced by the bearings, and what kind of bearings would be appropriate?

IV. LOADS ACTING OVER THE MAIN SUPPORT BEAM

A survey of published papers reveal a few basic factors that cause and experience different loads during most operations. First, the actual load experienced by the tool depends on the contact area between the tool and the workpiece. The greater the contact area, the more load. The next factor is the feed rate, the speed at which a tool is being moved towards a workpiece. The feed rate proportionally increases the forces experienced, especially tangential to the tool. Finally, the type of material being worked on matters [2], [7]. During the painting process, the nozzle, spray the paint at a certain distance away from the workpiece so that a large area of the workpiece is painted. Since there is no contact between the tool and workpiece the force due to the contact, feed rate and type of material do not come into effect.

Apart from these discussed, the end effector to be nozzle has its own weight and the capacity of the fluid container to carry the paint constitutes the load. Therefore the weight of the nozzle head, actuation systems, and paint delivery system cause the deflection over the beam.

In order to accurately position the nozzle the deflection of the beam should be minimized. To achieve this target the beams are assumed to be rigidly supported at the ends. This assumption should be valid if the support columns of the beam are made more rigid than the beam.

The design of beams is dependent upon the Magnitude and type of loading, length of the beam, Material of the beam, Shape of the beam cross-section. The figure shows the free-body diagram of the beam. A fixed beam of length 500mm with a concentrated load of magnitude 200N at the center is subjected to both bending and torsional moments. Conventionally used material for linear shafts in linear guideway is structural steel which has an elastic modulus of 200GPa and Poisson’s ratio 0.3. The diameter of the circular cross-section is obtained by solving the formulae. The diameter of a solid shaft subjected to both bending and torsional moments can

$$d^3 = \frac{16}{\pi . \tau}\left[\sqrt{(k_b M_b)^2 + (k_t M_t)^2}\right]$$

be obtained from: $y_{\max} = \frac{W\ L^3}{192\ E\ I}$

$$I = \frac{\pi . d^4}{64}$$

Solving for all these equations gave a set of values for M_b, M_t, d, I and y_{max}. For standard cases of loading, the amount of allowable deflection is expressed as a proportion of the member’s length, i.e. 1/180, 1/240 or 1/360 of the length [6].

d = 12.7mm

I = 1276.982mm^4

y_{max} = 0.4855mm

V. CAE ANALYSIS

It will be the best choice to use two linear shafts solution as most of the existing linear guideway designs consist of a lead screw in the middle with two linear shafts to support it. This advantage of this design is verified using element analysis done using ANSYS. The elements of the mesh are considered to be isotropic in nature and the material properties for structural steel are used to solve the problem. The support beam with a single rod and two rods are analyzed for their deflection and stress developed in the material and the results are shown in Table I.

Table i. Cae analysis result

	Deflection, mm	Stress, MPa
Single Rod Design	0.48327	64.108
Double Rod Design	0.20526	24.929

The results show that the deflection and the stress values for the double rod geometry is reduced. Comparing the maximum allowable stress for the material the design is safe with a factor of safety 1.5. Therefore, it is clear that the choice of the parameters for the beam is suitable for the application.

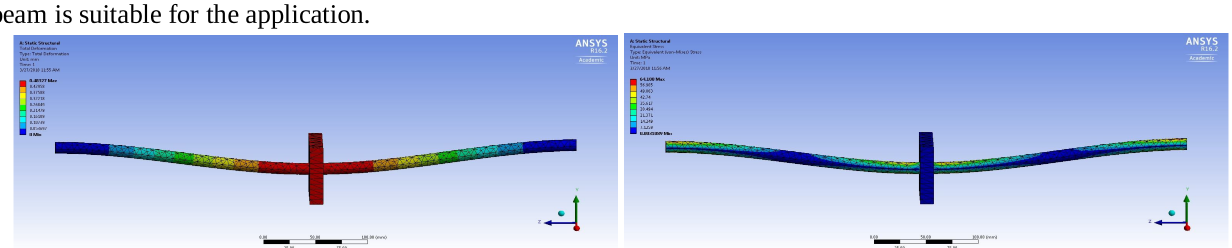

Fig. 2 Deflection and Stress result of beam with single rod

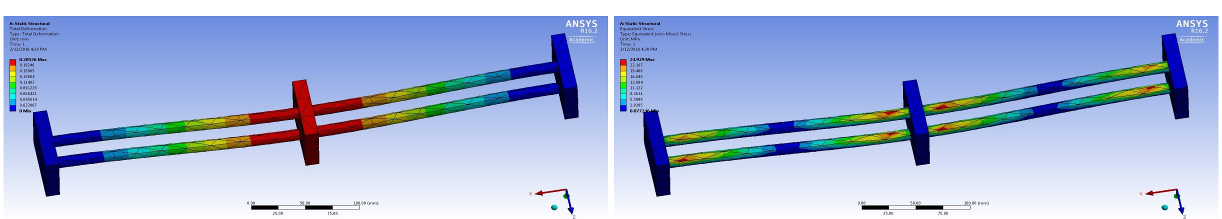

Fig. 3 Deflection and Stress result of beam with double rod

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VI. LEAD SCREW

The Lead screws also known as translation screws are used to actuate the linear motion along the axes. The nut has axial motion against the resisting axial force while the screw rotates in its bearings. One complete turn of a screw thread is imagined to be unwound, from the body of the screw and developed to form an inclined plane as shown in Figure. The parameters of the screw are the pitch diameter, p, lead of the screw, number of starts, n, lead angle, α and coefficient of friction, μ.

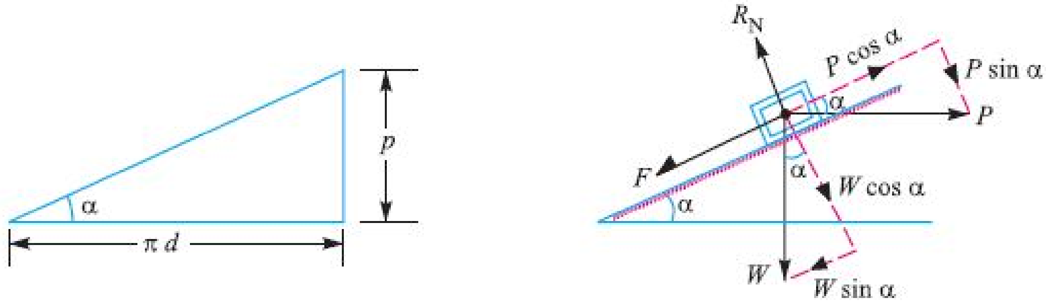

Fig. 4 Free body diagram of leadscrew

The forces acting on the screw are the load, the driving force, normal contact force and friction force. In order to determine the driving force required to raise or lower the load along the plane, the system is assumed to be in a state of rest. At equilibrium the forces in the horizontal and vertical directions are equated to zero.

$$\sum f_x = o \Rightarrow \quad P\,Cos\alpha = F + W\,Sin\alpha$$
$$\sum f_y = o \Rightarrow \quad R_N = WCos\alpha + P\,Sin\alpha$$

Since $F = \mu . R_N$

Solving the above equation for the driving force, $P = W\left[\dfrac{Sin\alpha + \mu\,Cos\alpha}{Cos\alpha - \mu\,Sin\alpha}\right]$

For trapezoidal threads, the coefficient of friction is substituted as $\mu_1 = \mu$. It depends on the value of the helix angle, β. Where $2\beta = 30°$

$$\mu_1 = \frac{\mu}{Cos\,\beta}$$

The dimensions of the leadscrew is shown in Table II.

TABLE II. Lead screw dimensions

	Major Diameter D	Minor Diameter d	Pitch p	Stress Area A_c
	mm	mm	mm	mm^2
Coarse M16	16	14.701	2	157

For single start screws, the lead of the screw is same as its pitch. Using pitch and minimum pitch diameter determine the lead angle, α of the screw.

$$\tan\alpha = \frac{L}{\pi\,d}$$

Assuming the coefficient of friction, $\mu = 0.15$ commonly used for steel screw and bronze nut the driving force required to raise the load over the step angle is determined using the above equation. The torque to be supplied to achieve the driving force is determined using.

$$T = \frac{P \cdot D}{2}$$

VII. CONCLUSION

A suitable design for the painting station is done. The required geometry of the beam to support the nozzle is modelled and the structures are verified using ANSYS analysis. The required torque on the leadscrew to withstand the loads are determined. Designing a suitable microcontroller unit to control the position of the end effector the machine can be implemented for operation in industries. The machine eliminates the hazards caused due to the painting chemicals to the human and reduces the time and effort consumed in repeated work.

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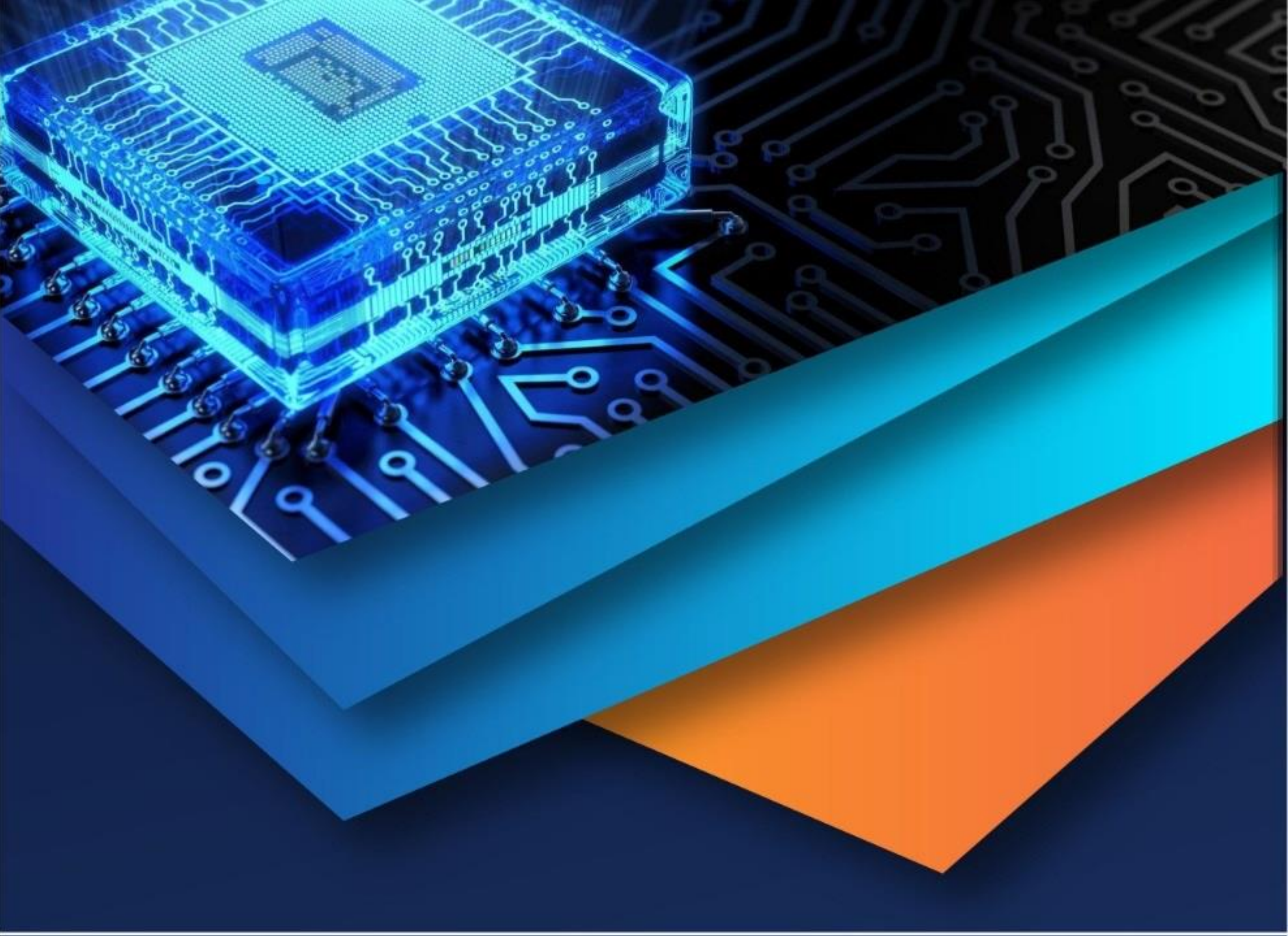

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