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Design and Analysis of Pneumatic Clamp for Turn Mill Application

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Abstract

The system which works using compressed air as working fluid is the pneumatic brake system. Pneumatic clamps are used in air actuated mechanisms to operate the clamping action. Pneumatic clamps are the ideal one in quick operation and economical to use in short run jobs. The pneumatic clamp structure should be designed to resist vibration under various performance conditions. The purpose of this work is design and analysis of pneumatic clamp to support milling operation on turn spindle. The 3-Dimensional Modelling of pneumatic clamp is done using Solid works 2016 software and Finite Element Analysis is performed using ANSYS workbench 15.0.7 software. Boundary conditions are applied as the base fixed and moment at the end of the shaft which is clamped to the spindle of lathe. Expected deflection of pneumatic clamps shaft is 20µ, however the deflection from the numerical solution is 15.85µ. Pneumatic clamp working frequency is 0.5 Hz and from the modal analysis, it is found that no frequency is falling near to the working frequency. Therefore, resonance does not occur for these conditions. Analysis results of deflection are compared with theoretical results. It is found that percentage error are in the permissible limits to validate the model.

Keywords: Air brake system, Pneumatic clamp, Modelling, Static structural analysis, Modal analysis.

Introduction

Pneumatic clamps are used in air actuated mechanisms to operate the clamping action. They are the ideal one in quick operation and economical to use in short run jobs.The main function of pneumatic clamp is to stop the turn spindle while milling operation is running on the same spindle. Stopping action of the spindle is performed by pneumatic brake system that uses compressed air as a working fluid. Pneumatic brake or a compressed air brake system is a kind of frictional brake for machines in which compressed air presses the piston to apply the pressure on the brake disk to stop the moving part. Turning and milling operations are the most commonly used machining operations to produce cylindrical and prismatic parts. After turning operation, milling operation is to be performed.To carry out milling operation on turning spindle, work piece has to be stationary and tool has to rotate. For this purpose an external clamp is required to make work piece stationary. The scope of present work is to design and analyse pneumatic clamp for turn mill application.

Fanping Bu *et.al.* [1], have carried out work on pneumatic brake systems that use compressed air as the energy medium in most of the buses and trucks now a days. This work shows the feasibility of giving a smooth precision stopping brake control system in view of a conventional pneumatic brake mechanism. Rakesh Chandmal Sharma*et.al.* [2], have carried out work on braking system which is used in railway industry. Brake control system is a basic component keeping in mind the end goal to retard and stop the railroad vehicle in least possible time. The paper discusses about the different braking control systems utilized as a part of railroad vehicles. Tadeusz Piechowiak [3], has carried work on overall breaking efficiency of cargo train and modelling of the discrete braking control elements on locomotives. The paper gives detailed description of the author's modelling methods used for solving problems related to railway pneumatic brake control system. The brake control models takes into account air wave phenomena which includes viscosity of air. Le He *et.al.* [4], have carried out work on vehicle brake system and presented the dynamic model of air brake system.The key components of air brake control system such as brake valve, relay valve, and brake chamber are constructed on the bases of standard pneumatic components. Using the key components the integrated air brake system is built, and the simulation results show dynamic characteristics of air brake control system. Shankar C Subramanian *et. al* [5], have carried work on air brake system in commercial vehicles andpresenteda model based diagnostic system for air controlled brakes. S Mithun*et.al.* [6], have worked on pneumatic brake system for heavy vehicles. The paper describes the brake control system products that consists of the actuating valves, control valves, actuators and foundation brake system. Ravi Ingle *et. al.* [7], have carried out work on reversed breaking system and presented the ways to achieve low cost automation for same set up.UmutKaraguzel*et. al.* [8], have worked on turn milling which is relatively new machining technology and that is used to perform cutting of symmetrical or non-symmetrical rotational parts. Dr. S K Choudhury *et. al.* [9], have carried out work on turn mill on the machining of symmetrical work piece.

After studying the available research papers in the field of air braking system and turn mill it was found that, pneumatic air braking concept can be applied to the operation of turn mill. The literature survey of pneumatic clamp was carried out, in order to understand the selection of methodology for the design of pneumatic clamp for turn mill application. From the literature review, the common objective was to find proper way for design and analysis of pneumatic clamp for turn mill application. In order to achieve this, we used some inputs from some papers which are referred above. Some of the authors used the concept of air braking systems and some of them have used concept of turn mill application. Based upon the literature survey the concept of pneumatic clamp is considered for the design.

Methodology

It is a systematic method that includes CAD modelling, FE modelling, loading and boundary condition, analysis and analytical approach.The methodology of the current research work involves mainly two kinds of independent solution such as:

Analytical solution:

The analytical solution is a generic process, which is the combination of the power of the scientific method with the use of formal process to solve any type of existing problems. Analytical methods uses exact thermos to solve any type of existing problems.

Numerical solution:

ANSYS is the numerical software commonly used to perform various types of analysis. The software works on the principle of Finite Element Method (FEM) approach.

The various steps involved in the design and analysis of pneumatic clamp for turn mill application are:

- Analytical calculations for factor of safety is carried out for the parts to check safety.
- Analytical calculations for deflection was carried out to check the maximum deflection of shaft in operating condition.
- Modelling of pneumatic clamp was made using the solid works 2016 and assigned material properties.
- The model was imported from the solid works to the ANSYS workbench.
- The static structural analysis and modal analysis was performed using software ANSYS workbench 15.0.7.
- Meshing and Boundary conditions were applied to the model.
- Conclusions were drawn based upon the comparison of analytical and numerical results for the model.

Design considerations for pneumatic clamp

Specifications

Pressure, $P = 5$ bar $= 5\times10^5$ Pa

Clamping torque, $T_c = 400$ N-m

Clamping torque

Thrust force, $F_{th} = PA = P \times \frac{\pi}{4} \times D_p^2 = 5\times10^5\times0.03142$

$= 15707.963$ N

Where $D_p = 0.2$ m (diameter which faces air)

Thrust force, $F_{th} = 15707.963$ N

Mean radius:Contact radius between brake disk and piston.

Brake disk contact radius, $r_b = 140$ mm

Piston contact radius, $r_p = 100$ mm

Mean radius, $r_m = \frac{r_b + r_p}{2} = \frac{140+100}{2} = 120$ mm$= 0.12$ m

Tangential force: $F_t = F_{th} \times \mu$

Tangential force, $F_t = 15707.963 \times 0.15 = 2356.1945$ N

Where co-efficient of friction, $\mu = 0.15$

Friction is on two surfaces, hence

Total tangential force, $F_t = 2356.1945 \times 2 = 4712.3889$ N

Clamping torque, $T_c = F_t \times r_m = 4712.3889 \times 0.12 = 565.4867$ N-m

Calculation for deflection

Convert the stepped shaft into uniform shaft.

Make uniform diameter and find length of equivalent shaft up to the overhanging part of shaft (i.e. considered as cantilever beam).

Length of equivalent shaft, L_e

$L_e = l_1 + l_2 \left(\frac{d_1}{d_2}\right)^4 = 50 + 30 \left(\frac{50}{64}\right)^4 = 61.1759$ mm

Diameter of equivalent shaft, $D_e = 50$ mm

Deflection of cantilever beam $Y_A = \frac{ML^2}{2EI}$

Where, M = moment, N-mm

L = length of shaft where moment is applied, mm

E = Young's modulus, GPa

$$Y_A = \frac{565486.7 \times 61.1759^2}{2 \times 200000 \times 306796.158} = 0.01725 \text{ mm}$$

The deflection of shaft is found to be 17.25 µ by analytical method.

Model of pneumatic clamp

The pneumatic clamp assembly model was made using solid works 2016 software. The pneumatic clamp model isshown below in Fig2.1& Fig. 2.2:

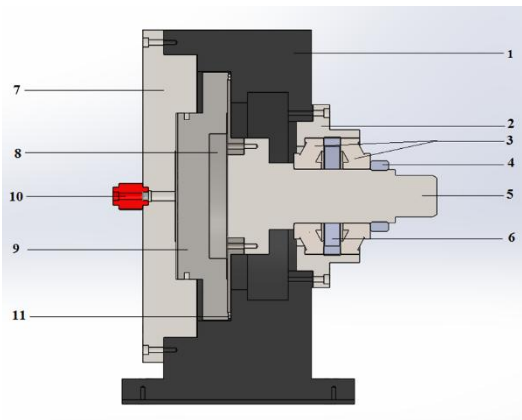

Fig. 2.1. Section view of model

1. Main housing
2. Bearing housing
3. Taper roller bearings
4. Lock nut
5. Shaft
6. Bearing spacer
7. Base flange
8. Brake disc
9. Piston
10. Compressed air inlet
11. O ring

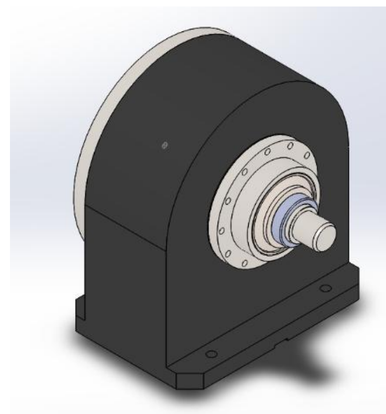

Fig. 2.2. Isometric view of model

Finite element analysis of pneumatic clamp

Data collection for Analysis

ANSYS Workbench 15.0 is used to perform analysis for the model of pneumatic clamp.

1. Material selection for each parts.
2. Material properties.

Material selection

- ➢ EN8 forShaft, Piston, Base flange, Bearing housing and Bearing spacer.
- ➢ Spring Steel for Brake disk.
- ➢ Grey cast iron for Main housing.
- ➢ Rubber for O ring.
- ➢ Low carbon steel for Taper roller bearing.

Material property

Table 3.1. Material properties defined in ANSYS workbench [10], [11]

Material	Density (Kg/m^3)	Young's modulus E (GPa)	Poisson's ratio
EN 8	7850	200	0.29
Spring Steel	7850	190	0.29
Rubber	7520	0.001	0.47
Grey Cast Iron	7200	110	0.28

Analysis of pneumatic clamp

- ➢ Building the pneumatic clamp model in solid works and then import into the ANSYS software.
- ➢ Defined the material properties for this model and apply the contacts properly.
- ➢ Defined and assigned the material properties to the parts.
- ➢ Meshed the existing model.
- ➢ Define the boundary conditions.
- ➢ Apply the moment, calculated analytically.

- Solve/Run the analysis & get the results.

Static structural analysis of pneumatic clamp

A static structural analysis is used to calculate the effects of steady state loading conditions ignoring the effects of the inertia and the damping. The CAD model of the pneumatic clamp is shown in Fig. 3.1 and meshed model was shown in Fig. 3.2.

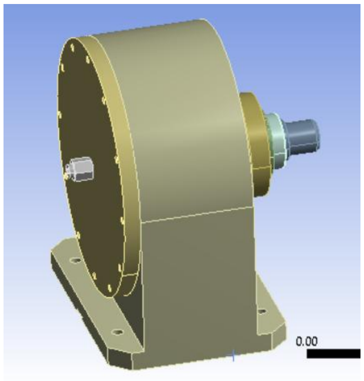

Fig. 3.1. CAD model of the pneumatic clamp

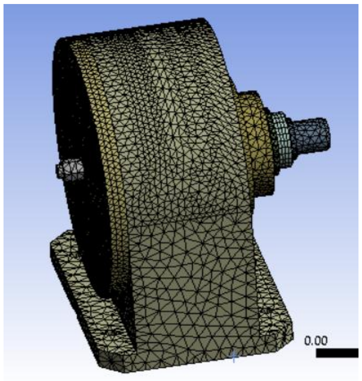

Fig. 3.2. Meshed model

Table 3.2. Specifications of meshing

Number of elements	177818
Number of nodes	307151
Mesh type	Solid Tetrahedrons

Boundary conditions for pneumatic clamp:

Fixed support for pneumatic clamp is shown in Fig. 3.3 and moment applied on shaft is shown in Fig 3.4.

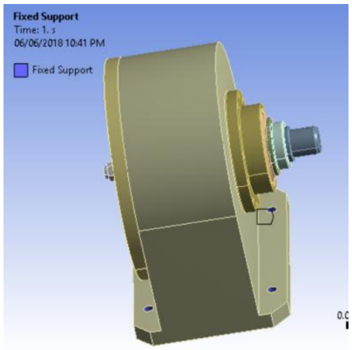

Fig. 3.3. Fixed support

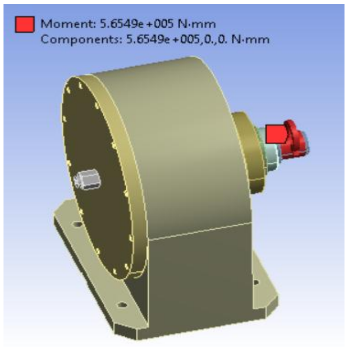

Fig. 3.4. Moment applied on shaft

Results obtained from the solver

Total deformation obtained from ANSYS workbench is shown in Fig. 3.5 and equivalent Von-mises is shown in Fig. 3.6

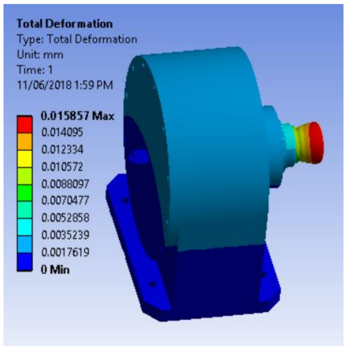

Fig. 3.5. Total deformation

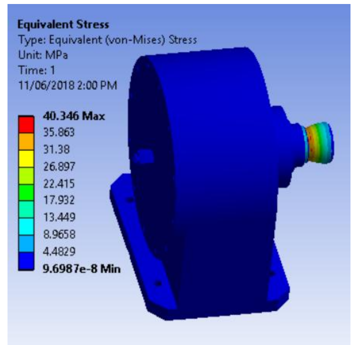

Fig. 3.6. Equivalent Von-mises stress

Modal analysis of pneumatic clamp

Modal analysis is the process of determining the inherent dynamic characteristics of a system in the form of natural frequencies, mode shapes, damping factor and using those to formulate mathematical model for its dynamic behaviour. The credit of coining the term modal analysis goes to Kennedy and Pancu, in 1947.

Boundary conditions are same as static structural analysis.

In design phase of assembly, perform fix-force modal analysis to understand how the body behaves when it is fixed and moment applied at free end of shaft. Here we have extracted 6 modes.

Results obtained from the modal analysis: Modal analysis results are shown in Fig. 3.6.

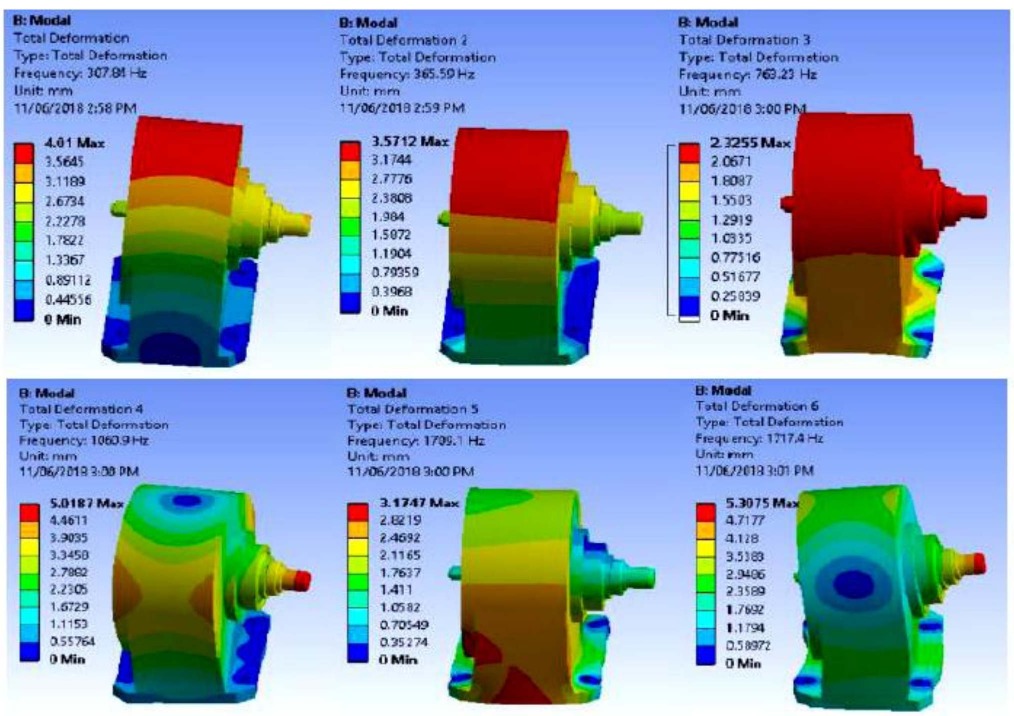

Fig. 3.6. Mode shapes for fix-force modal analysis

Table 3.3. Mode type for fix-force modal analysis

Mode No.	Frequency, Hz	Mode type
1	307.84	Bending (X-axis)
2	365.59	Bending (Z-axis)
3	763.23	Axial Compression (Y-axis)
4	1060.9	Twisting
5	1709.1	Twisting
6	1717.4	Twisting + Bending

Results and discussion

Static structural analysis result

Table 4.1. Comparison of analytical and numerical solution

Sl. No.	Analytical Deflection (mm)	Numerical Deflection (mm)	% Error
1	0.01725	0.01586	8.058

Calculation for percentage of error

% Error = (Analytical value −Numerical value) / (Analytical value) × 100

$$= \frac{(0.01725\ -0.015857\ )}{0.01725} \times 100 = 8.075\ \%$$

From the above result, it is found that the analytical deflection is in good agreement with FEA results.

Modal analysis result

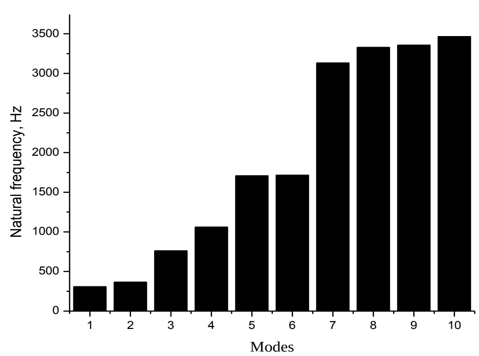

Fig. 4.1. Natural frequency for forced modal analysis

Pneumatic clamp working frequency is 0.5 Hz. From the above results it is found that no frequency falling near to working frequency. Therefore, the proposed dynamic structure satisfied the required condition.

Conclusion

The major outcomes from the work are:

- From the results of static structural analysis, deflection obtained from analytical solution is in good agreement with FEA results.

- Expected deflection of pneumatic clamps shaft is 20µ, however the deflection from the numerical solution is 15.857µ. Hence the result is satisfied.
- For the case of rigid body motion in free-free modal analysis, first three or six modes are having zero natural frequency.
- Pneumatic clamp working frequency is 0.5 Hz. From the extracted 12 modes, it is found that no frequency is falling near to the working frequency. Therefore, the proposed dynamic structure satisfied the required conditions.

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