Design and manufacturing of a portable pneumatic material handling equipment

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Abstract: Many of the production and manufacturing firms adopt workspace automation for fast and economic production. Automation can be accomplished through hydraulics, pneumatics and robotics. This paper presents the design and manufacturing of a portable pneumatic material handling system that can rise and move weight up to 3 kg. Such a machine can be used as a transport or positioning equipment in small scale production units. The design procedure includes the design of pneumatic cylinders, gears and arms. Different components were manufactured according to the designed data and finally the assembled pneumatic framework is tried with the required weight.

1. Introduction

Material handling is the art and science of moving, packing and storing of products. Material handling is one of the most lucrative areas for cost reduction in an average manufacturing plant. It offers an opportunity for the reduction of production cost. Now a days all industries are mechanizing various material handling activities for fast and economic production. Automated systems are very fast and precise than in hand operations. Automation can be achieved through hydraulics, pneumatics, robotics, etc. of these sources, pneumatics form an attractive medium for low cost automation. Pneumatic systems are very economic and simple in operation. Servo Pneumatic systems offers accurate position control as compared to hydraulic and electro mechanical drives [1]. Appropriate mathematical models needs to be used for smooth and precise position control of pneumatic actuators [2][6]. Numerical methods are used widely now a days to provide design guidelines to pneumatic conveying systems [7]. The major drawback of pneumatic drives is the nonlinear nature of drive operation which can affect the dynamics of equipment [8]. This nonlinear nature can be reduced by implementing efficient position control mechanism to the pneumatic actuators [3][9]. Another issue with pneumatic material handling system is the difficulty in fault detection. Pneumatic material handling system may have hundreds of actuators and sensors, hence quick detection of faulty component is extremely difficult [4]. The efficiency of pneumatic equipment can be improved in many ways. One way to improve efficiency is the use of compressed air storage and recycling [5]. The exhaust gas from one pneumatic component is stored in an efficient way and is reuses to power another component.

The current work is an effort to design and manufacture a low cost pneumatic material handling equipment suitable for a small scale production unit. Such an equipment can be used for many applications like shifting hot work material, positioning welding materials etc in production units.
1.1 Components of Pneumatic material handling systems
Pneumatic material handling system consist of a piston-cylinder actuator, direction control valves, pressure gauges, gear mechanisms and finally air compressor to supply high pressure air. Compressor is the major component that supplies air at required pressure. It can be a two stage or two cylinder reciprocating air compressor. Pressure gauges are used to measure and control pressure at various points in the fluid connection wires. The to and fro movement of actuator cylinder can be controlled with direction control valves, which regulate the air flow to both sided of the piston. So also one may need to control the pressure and stream rate to produce the coveted level of constrain and speed of actuators.

An actuator is a device that is used to apply a force to an object. Direct or linear actuators are used to apply drive in a straight line and rotary actuators are used to move object in round ways. Direct actuators are of two types - single acting cylinder and double acting cylinder. In single acting cylinder, air moves the piston in one direction only, the return movement is effected by an external force. But double acting cylinder offers piston movement in both direction.

2. Methodology

2.1 Design of Pneumatic double acting actuator cylinder.
Pneumatic material handling system needs four pneumatic actuators. Three cylinders are to facilitate horizontal, vertical and rotary motion of the arm and one cylinder for the arm gripping action. All cylinders are of same type of design with only change in applied force; and taken from the product catalogue (Janatics pneumatic products [10]). According to the applications, the forward and return stroke of the piston has to be controlled with some time interval. So double acting cylinders are preferred. This time interval cannot be achieved by single acting cylinders.

2.1.1. Design of gripper cylinder.
This material handling system is designed to raise 3 kg weight; hence the maximum force acting on the gripper arm is 30 N. Hence force to be exerted is 30 N. \( d_1 \) is the cylinder diameter (bore diameter) and \( d_2 \) is the piston rod diameter.

**Bore diameter:**
Gauge pressure in the cylinder = 1.2x10^5 N/m^2 (As per the available compressor rating)
Force =  Pressure x Area= 30 N
Area of the cylinder \( (A) = \frac{\text{Force}}{\text{Pressure}} = 250 \text{ mm}^2 \)
Hence the bore diameter \( (d_1) = 17.84 \text{ mm} \).

From ‘Janatic Pneumatic’ product catalogue we can selected a double acting pneumatic cylinder of bore diameter 20mm. For 20mm bore diameter, Corresponding rod diameter \( (d_2) = 8 \text{ mm} \).

2.1.2 Design of cylinder to provide vertical motion to arm.
Force to be exerted is 110 N (including object weight (30 N) and anticipated arm material weight).
Based on the same procedure: Bore diameter = 34.1 mm
From ‘Janatics Pneumatic Products’ catalogue we have selected 40 mm bore diameter cylinder and Corresponding rod diameter is 16 mm.

2.2 Design of gears (rack and pinion -to provide rotary motion to arms)
A rack and pinion gear system is provided at the base of the arm support that enables the arm rotary movement. Rack is attached to the pneumatic cylinder rod, so the actuation of cylinder provided a linear motion to the rack and the pinion convert this to rotary motion. A ball bearing is also provided at the bottom of the pinion to facilitate easy rotation of the arm. Ball bearing also provides support to the pneumatic system arm.
2.2.1 Design of pinion
From design data book [11],

\[ d_{\text{min}} > \left( \frac{0.59}{\sigma_{c_{\text{max}}}} \right) \left[ \frac{M_t}{\left( \frac{1}{E_1} + \frac{1}{E_2} \right)^2} \right]^{\frac{1}{2}} \]

Where \( d_{\text{min}} \) is the minimum diameter of pinion and \( \sigma_{c_{\text{max}}} \) is the maximum contact compressive pressure.

Young’s modulus, \( E_1 = E_2 = 130 \times 10^9 \text{ N/m}^2 \) (cast iron)

The minimum diameter of the pinion is calculated to be 38.7 mm. We have taken the standard diameter of pinion as 40 mm.

From the design data book, specifications of the pinion: Material: cast-iron
Outside diameter: 40 mm, Circular pitch: 4.7 mm, Tooth depth: 3.375 mm, Module: 1.5 mm
Pressure angle: 21°, Pitch circle diameter: 37 mm, Addendum: 1.5 mm, Dedendum: 1.875 mm
Circular tooth thickness: 2.355 mm

2.2.2 Design of rack
Rack length is 62.5 mm for a rotation of 180°.
Specifications of the rack: Material: cast iron, Module: 1.5 mm, Cross-section: 75x25 mm
Rack teeth is adjusted for 125 mm. The designed component dimensions are provided in table 1.

Table 1. Dimensions of different components.

| Component             | Parameter          | Designed value |
|-----------------------|--------------------|----------------|
| Gripper cylinder      | Bore diameter      | 20 mm          |
|                       | rod diameter       | 8mm            |
| Vertical cylinder     | Bore diameter      | 40 mm          |
| (cylinder provided    |                    |                |
| for arm vertical      |                    |                |
| motion)               |                    |                |
| Rack and Pinion       | Pinion diameter    | 40 mm          |
|                       | Rack length        | 62.5 mm (for 180° rotation) |

2.3 Material of construction
Materials for different parts are selected based on the machinability and weight considerations. Table 2 shows the materials selected for various parts.

Table 2. Materials selected for different parts.

| Part          | Material   | Part | Material |
|---------------|------------|------|----------|
| Gripper cylinder | Aluminium | Block | MS       |
| Rack          | Cast Iron  | Frame | MS       |
| Gripper arm   | MS         | Pinion | Cast Iron |
2.4 Description of Assembly block
The assembly unit shown in figure 1(b) consists of a base block, rack and pinion and gripper arms. One pneumatic cylinder is mounted horizontally on the base block with rack and pinion assembly connected to the rods as shown in figure 1(a). Another pneumatic cylinder is mounted vertically over the base plate to move the arm in up and down position. The horizontal cylinder is mounted on the block of the vertical cylinder horizontally to increase length of the arm with a block and end plate provided at the end position. The gripper cylinder is mounted on the horizontal cylinder block as shown in figure 1(c) in an inclined position of angle 30° to actuate the gripper. The piston rod of gripper cylinder is connected to the one side of the gripper.

3. Results and discussion
Different parts of the material handling systems are manufactured based on the designed data (except pneumatic actuators which was purchased from vendor) which weights 70 kg. Figure 1(a) shows the assembled Pneumatic material handling system. The equipment consists of four pneumatic double acting cylinders to provide movement to different direction. The cylinder 1 (C1) is used to actuate the rack and pinion assembly by connecting piston rod of C1 to the rack, which is meshed with the pinion. By operating the cylinder C1, rack and pinion turns the whole assembly for 260°. By varying the length of the rack the turning angle can be altered. Vertical cylinder or cylinder 2 (C2) provides up and down movement to the arm. The vertical movement is limited to piston rod length. Horizontal cylinder or cylinder 3 (C3) is used to increase the arm length and the working area of the arm. Gripper cylinder or cylinder 4 (C4) is used to actuate the gripper arms. Control valves are provided to control the actuation of different pneumatic cylinders, and there by control the movement of the arm. The entire arm structure is resting over a ball bearing which provides support to the arm.

3.1 Equipment testing
A 3 kg metallic block is used for testing the equipment. The block was kept on the floor at 130° left to the equipment. Then the arm rotated to 130° angle and block gripped with gripper arm by actuating gripper arm cylinder (C4). Next cylinders C2 and C3 were actuated to slowly rise the weight up to 1 m height. By maintaining the same height cylinder C1 is actuated till the arm rotates 260°. Finally all cylinders are deactivated to place the weight back on to floor.

![Figure 1. (a) Assembled Pneumatic material handling system (b) 3D model of Assembly unit (c) Gripper arm](image)

4. Conclusion
There is a variety of manual, semi-automated and automated material handling equipment and technologies available to aid in the movement, protection, storage and control of materials and products throughout manufacturing, distribution, consumption and disposal. All these material handling system are made for large scale production unit. Small scale production units cannot afford such high end high cost material handling system to aid production and manufacturing. In this work a
low cost portable material handling system is designed and fabricated with components available in
common market. This equipment consists of four direction control valves and four pneumatic actuators.
The application of pneumatics produces smooth operation and the work volume is produced within the
angle of 260° and the equipment is tried with weight up to 30 N. The equipment can rise weight up to
1m height. This equipment can be used for shifting hot work materials, holding welding materials
e tc in small scale production units. The capacity of the equipment can improve by providing high
capacity air compressor and pneumatic cylinders. Another factor that effect the performance of
equipment is gripper arm design.

5. References

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