Development of Self-Propelled Material Handling System

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Abstract. Material handling system is the vital pillar of manufacturing industries like food, textile, automobile, wood, and other batch type manufacturing system. Research carried out in past shows that material handling accounts for 36% of production cost. A novel material handling system is developed to cut the cost of material transfer and risk of injury. The proposed system consists a mechanism which can self-propel itself and effect the transfer of raw material from one place to another on a shop floor. Since the system is self-propelled, it eliminates external power source in contrast to other material handling systems. The newly developed material handling system utilizes gravitational potential energy of the material loaded on the system to get self-propelled along a straight line. The system returns to original position by retracing the path after unloading the material at the destination. The system not only reduces the energy consumption for material handling but also reduces risk of injury by reducing human interference. It can be used in small and medium size enterprise (SME) to cause improvement in productivity of plant which has limitation on utilization of resources like labour, energy, land and capital.

1. Introduction

Material handling systems are used in industry to safely transfer large volume of heavy materials. A study shows that in most of small and medium sized enterprises (SME) about 2/5th of manufacturing cycle time is spent on material handling. About 20–80% of the total cost is spent on transportation of material within the industry. Also, 30–40% of industrial accidents are cause during material transfer [1] [2]. Most of SME work with constraints like minimum number of technically skilled manpower, limited capital investment on advanced machineries and plant area. Study of existing material handling system reveals that, for employing such advanced systems high initial investment is necessary. Also, operation of automated systems incurs high running and maintenance cost. Dependent nature of SME on manual work, reduces plant productivity. Therefore, to improve the productivity of plant it is necessary to reduce time and effort required for transfer of material. Further, efficient energy consumption will maintain higher plant productivity. This need demands a low-cost automatic energy efficient material handling system suitable for SME. Innovative efforts are required to develop material handling system which improves labour productivity, energy productivity and capital productivity. Improving these partial productivities will cause rise in the value of products [3][4].

2. Concept generation
Conceptualized material handling system is shown in Figure 1. It has carriage mounted on 4 wheels. The carriage consists load plate resting on spring supports. When the material is loaded gradually on carriage, spring supports under the load plate gets compressed under the gravitational potential energy of load and slides the load plate downward. The downward motion of the load plate is used to drive a mechanism which propels the carriage in forward direction to reach destination point. The material is unloaded at destination point. Upon unloading, elastic potential energy stored in the spring supports during compression is released. The spring supports start extending towards original position causing the load plate to move up. During the extension of the spring support, same mechanism utilises elastic potential energy of spring to retrace the path and reach the start point. The material handling system is held in place by applying brakes to the wheels during loading and unloading process as indicated in the Figure 1. The loading and unloading process is gradual. The transfer of material does not involve any labour input. The energy to drive the mechanism is gravitation potential energy of load during forward motion and elastic potential energy in spring supports during backward motion.

![Figure 1. Concept of Self-Propelled Material Handling System.](image)

3. Development of virtual prototype

The Rack and pinion mechanism was developed and synthesized which can convert the gravitational potential energy of the material into elastic potential energy, as shown in Figure 2. Top end of the rack is rigidly fixed to bottom of load plate. Load plate is free to slid up and down along walls of the carriage. The spring attached to the bottom of rack compresses during loading operation. This compression is utilized for forward motion of carriage. Compression causes downward motion of rack and proportional rotation of the pinion attached to the rack. Rotation of the pinion is transferred to a large sprocket by using a gear train, as shown in Figure 3. The large sprocket is connected to the small
sprocket using a chain. The small sprocket is connected to the wheels of the carriage by mounting them on a common shaft. The rotation of pinion rotates larger sprocket through gear train and rotation of larger sprocket is transmitted to smaller sprocket by a chain. The rotation of small sprocket causes rotation of wheels moving the carriage towards destination point in straight line. Unloading at the destination releases elastic potential energy stored in spring support. Release of elastic potential energy causes extension of the spring. The extension of spring is transmitted to wheels of the carriage by reversing the motion of gear train and chain drive mechanisms. Because of reversal of driving mechanisms, carriage returns to start point by retracing the same path.

The sketches were put together to develop a digital prototype as shown in Figure 4. In virtual prototype load plate slides along the walls of carriage, this concept was updated to new sliding mechanism. The load plate is mounted on top of inner sliding bar. This inner sliding bar slides along the inner walls of outer hollow pipe to compress the spring is contained within the outer hollow pipe. Top end of spring is fixed to inner sliding bar and bottom end is fixed to base frame. Rack is rigidly fixed along the walls of inner sliding bar such that it does not interfere with sliding action of inner bar and outer pipe. Pinion is meshed with the rack. Pinion is mounted on a shaft which is held rigidly a bracket. The bracket also supports gear train and large sprocket. Larger sprocket transmits the motion to smaller sprocket using a chain drive. Smaller sprocket is mounted on driving axel of the carriage wheels.

![Figure 4. Digital prototype in SolidWorks software.](image)

4. Design and synthesis of driving mechanisms

Main components of material handling system are rack and pinion, spring support, Gear train and chain drive. These components are designed such that carriage can move 55 Kg load by 5 m along a straight path. Considering ergonomic needs during loading and unloading of material at the start and destination points, height of the carriage was calculated as 1 m [5] [6]. Four plastic wheels of 100 mm diameter were selected to guide and support the carriage. Sixteen revolutions of 100 mm diameter are required to travel 5m along straight line. This calculation was used to synthesize dimensions of smaller and larger sprocket of chain drive. Linear movement of rack is equal to deflection of spring under compressive load. The movement of rack is input for synthesis of gear train. The spring parameters were determined such that spring was strong enough to carry load of 55 kg during loading operation [7] [8]. Elastic potential energy stored in the spring during loading operation should be enough to overcome frictional forces during retrace; therefore, stiffness value was recalculated by considering sliding friction at various joints.

It was necessary to verify the analytical design of gear train by selecting 20MnCr5 as gear material [9] [10]. Finite Element Analysis was carried out using ANSYS R16.1 (Academic). The results of the FEA gave maximum total deformation at the tooth engagement interface as 0.0014 mm and maximum
von-mises stress at the tooth engagement interface as 7.6176 Mpa. Deformation and stresses in gear train components were below failure limits as shown in Figure 5.

![Figure 5. Deformation and stress analysis of gear train.](image)

Verification of rack and pinion design using ANSYS R16.1 (Academic) as shown in Figure 6, gave maximum von-mises stress at the tooth engagement interface as 25.354 Mpa and maximum total deformation at the tooth engagement interface as 0.0035mm. These values were within permissible limits for 20MnCr5 material.

![Figure 6. Deformation and stress analysis of rack and pinion.](image)

All other components such as base frame, bearing for shafts, shafts of gear train which transmit the motion were analytically designed [9] [10] [11]. Later the designs were verified in FEA software. Necessary modifications in the designs were made to make manufacturing and assembly operations feasible.

5. Fabrication of physical prototype

Part drawing process diagrams of all components were prepared and were fabricated. The final appearance of fully assembled material handling system is shown in Figure 7. Gear train, chain drive and all other moving components were lubricated to reduce friction.

![Figure 7. Physical prototype of Material Handling System.](image)
6. Results and discussion

Testing of material handling system was carried out by placing the weights on load plate. Observation sheet used is shown in Table 1. The distance travelled by the carriage and the time taken to travel that distance for each load was recorded. The material was then unloaded at the point where carriage stops. Time and distance during retrace of carriage is recorded. To understand the relationship between load placed on load plate, and the distance travelled under that load, a graph of Load (Kg) versus Distance travelled (m) was plotted as shown in Figure 8.

| Sr No | Load (kg) | Distance travelled (m) | Time taken by equipment (sec) |
|-------|-----------|------------------------|-------------------------------|
|       |           |                        | Forward motion | Backward motion |
| 1     | 18        | 0.2                    | 41              | 43              |
| 2     | 20        | 0.5                    | 38              | 40              |
| 3     | 25        | 0.7                    | 34              | 36              |
| 4     | 30        | 1                      | 32              | 32              |
| 5     | 35        | 1.6                    | 27              | 28              |
| 6     | 40        | 2.3                    | 24              | 24              |
| 7     | 45        | 2.9                    | 21              | 20              |
| 8     | 50        | 3.5                    | 19              | 17              |
| 9     | 60        | 4.1                    | 17              | 16              |
| 10    | 70        | 5                      | 15              | 13              |

Figure 8. Response of the Machine under various Loads

The graph of load versus linear distance travelled shown in Figure 8, indicates a linear relationship with an intercept on x-axis. Intercept represent the minimum load required to move the carriage. The value of intercept is found as 18 Kg which is required to overcome frictional forces. Further, Load of 70 Kg on load plate displaces the carriage by 5 meters. Time for forward motion and retrace was recorded and it was observed that for all loads, time for forward motion was lesser than that for retrace along same path, shown in Table 1.
7. Conclusion and future scope

A Working prototype of energy efficient self-propelled material handling system was designed and tested. It was intended for an operating range of 35 Kg to 55 Kg, whereas the operating range can be extended based on application of the product. Apart from using this system to transfer heavy raw materials between loading and unloading points, it can find its potential application in assembly lines in automotive industry. It can also find application in assembly lines of automobile industry to transport chassis of vehicle from one station to other station placed along nonlinear paths. Current material handling system is developed for straight line motion between two fixed stations. Further, the system can be modified to travel along desired curved path by incorporating suitable guiding mechanism, thus widening its scope of application in industry.

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