T4C-1 15.45

Proceedings of the 4th IEEE
International Symposium on Assembly and Task Planning
Soft Research Park, Fukuoka, Japan • May 28-29, 2001

Development of a Pneumatic Control Circuit for Weightless Material Handling with Air Hoists

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Abstract

Air hoists are widely used in handling of heavy materials in industry. Conventional air hoists necessitate the operation of manual switches for vertical motion, thus the operator has a difficulty in operating of the switches and handling of material at a time. To overcome such difficulty, this study develops a pneumatic control circuit for weightless material handling with air hoists. The pneumatic circuit memorizes the weight of load in terms of a pneumatic pressure. The pressure is then used as a feedback signal to achieve weightless handling of materials. To demonstrate the effectiveness of the proposed pneumatic circuit, handling forces and the response of the system for various material weights are examined through a series of experiments. The results show that the proposed pneumatic circuit for air hoists can be used in material handling with small manual operation force.

1. Introduction

Compressed air has been widely used in wide range f engineering fields such as mining, construction, and anufacturing. Air hoists transform the energy of mpressed air into mechanical energy, which enables hoists to lift heavy materials. In general, compressed has properties of low density, high compressibility, and low response.[1] Also, dynamic behavior of compressed air takes highly nonlinear characteristic resulting in the difficulty of modelling and analysis.[2] On the other hand, the energy of compressed air can be easily stored due to its high compressibility. Also, pneumatic actuators are safer than both hydraulic ones and electrical ones in that they have no danger of oil leakage, fire and electrical shock.

Currently, manually-operated air hoists adopts a pneumatic cylinder type or an air motor type. Some cylinder-type air hoists uses weight-balancing mechanism that operates only when a material is loaded and lifted. Such air hoists require manual operation of switches for ascending and descending motion. In this case, the operator should handle the load and operate the switch at a time with his hands. Such manual operation may cause danger especially when handling a big and heavy material; the material can be tilted and dropped due to its instability. Therefore, it is necessary to develop a weightless material-handling system that eliminates the operation of up/down switches to overcome such danger. The weightless handling means achievement of balancing between the weight of load and the pneumatic pressure of the air hoist.

Up to now, some methods for balancing have been reported: an active gravity compensation method[3], a counter mass mechanism[4]-[6], a spring mechanism [6], and a pneumatic cylinder mechanism[7]. The air hoist used, a kind a pneumatic cylinder, is manually operated, thus a fully automatic balancing mechanism cannot be applied. Also, the air hoist uses only compressed air, thus it is strongly recommended that a pure pneumatic control circuit should be developed.

For such purpose, this study aims to develop a pneumatic circuit for weightless control of air hoists using compressed air. With the pneumatic circuit, manual operation is performed through three modes: clamp mode, balance mode and unclamp mode. To move a material from a place to another place, the operator should previously clamp the material to a clamp jig by operating a switch. When the clamp switch is on, the first mode, clamp mode, is activated; compressed air is charged into the clamp cylinder and the air hoist successively to move the material upward. As soon as the clamp switch is off, the balancing mode is activated; the pneumatic circuit memorizes the weight of load through feedback of the pneumatic pressure in the air hoist. Such memory of the material weight is then used for achieving weightless material handling with a P-P (Pneumatic-to-Pneumatic) proportional valve. In this mode, the operator can move the material upward or downward with small manual force. The unclamp mode is activated when the unclamp switch is on; the material is safely unloaded from the jig only after the compressed air is fully discharged from the air hoist.

To demonstrate the effectiveness of the proposed circuit, handling forces and the response of the system for various material weights are examined through a series of experiments. The results show that the proposed pneumatic circuit for air hoists can be used in material handling with small manual operation force.

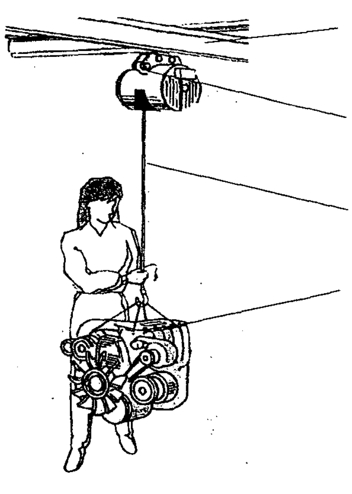


Fig. 1. The air hoist system

2. Air Hoist System and the Control Circuit

2.1 Air Hoist System

Air hoist system consists of the rail system, the air hoist, the wire, and the clamp jig as shown in Fig. 1. The rail system is a guide for the air hoist to move manually in the horizontal direction. The clap jig, connected to the air hoist with a steel wire, fixes a material to be moved. The air hoist, shown in Fig. 2, is an actuator which transforms the energy of compressed air into mechanical energy. Compressed air is charged into the housing of the air hoist, and pushes the piston with a pneumatic pressure. The horizontal motion of the piston is transformed into rotation of the reel, which is connected to the nut rotated around the ball screw fixed to the housing. Finally, the reel rotation winds the wire to lift the load. When compressed air is discharged from the air hoist, the load is lowered by its own weight.

The payload of the air hoist is dependent on its dimension and the pneumatic pressure. The reel is regarded as a thread with the effective diameter d_r and the pitch t. When neglecting friction between all components, the maximum payload W_{max} is evaluated by

$$W_{max} = \frac{Pt}{4\,d_r}(\,d_1^{\,2} - \,d_2^{\,2}) \qquad (1)$$

where P is the pressure of compressed air, d_1 is the inside diameter of the housing, and d_2 is the outside diameter of the ball screw. Given the dimension of the air air hoist shown in Table 1 and supply pressure 6 bar, the maximum payload is calculated as 780N.

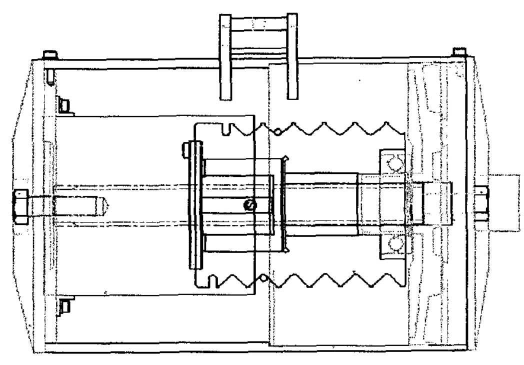


Fig. 2. Schematic diagram of the air hoist

Table 1. The dimension of the air hoist (mm)

Reel pitch (*t*)	effective diameter of the reel (d_r)	Inside diameter of the cylinder (d_1)	Outside diameter of the ball screw (d_2)
25	128	156	39

2.2 Pneumatic circuit for weightless control

The pneumatic circuit for weightless material handling is to be developed in such a way that the circuit keeps track of the pressure of compressed air of the air hoist, and maintains the pressure corresponding to the weight of load throughout the handling operation. To this end, three operation modes are introduced for weightless material handling: clamp mode, balance mode and unclamp mode. The sequence of material handling and the corresponding operation modes are shown in Fig. 3.

2.2.1. Clamp mode

Prior to moving a material from a place to another place, the operator should fix the material to a clamp jig by operating a manual switch. When the clamp switch is on, the clamp mode is activated. In this mode, compressed air is charged into the clamp cylinder and the material to be moved is clamped. Then, compressed air successively charged into the air hoist to lift the material.

2.2.2 Balance mode

As soon as the clamp switch is off, the balancing mode is activated. The pressure in the air hoist is fed back to a P-P (Pneumatic-to-Pneumatic) proportional valve via pilot port of the valve. Approximately, the pneumatic pressure corresponds to the weight of the material. The P-P valve plays a role that the outlet pressure is the same as the pilot pressure. Thus, in this mode, balancing between the weight of the material and the pressure in the air hoist is achieved. Then, the operator can weightlessly move the material upward or downward.

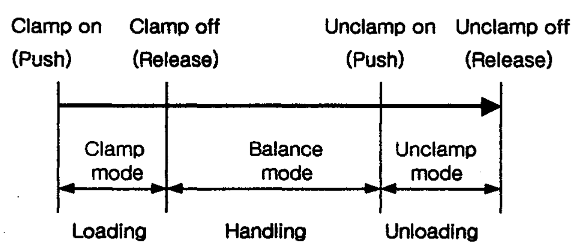


Fig. 3. The relationship between the material handling sequence and the operation modes

2.2.3 Unclamp mode

The unclamp mode is activated when the unclamp switch is on. In this mode, the compressed air is discharged from the air hoist to unload the material. If the material is to be unclamped under high pressure of the air hoist, weight balance is destroyed at that moment for the air hoist to abruptly move upward. To prevent this undesirable operation, this mode adopts a safe function with which the material is safely unclamped from the jig only after the compressed air is fully discharged from the air hoist.

2.2.4. Pneumatic circuit

To implement the weightless control of the air hoist, a pneumatic circuit is designed with consideration of the three operation modes. The pneumatic circuit, shown in Fig. 4, is classified into two parts: the balancing control circuit at the upper and the clamp/unclamp circuit at the lower.

The air hoist, a kind of pneumatic cylinder, in the figure plays a role of the main actuator. The direction of the air hoist motion is controlled by a 3/2-way valve. The pressure of the air hoist is controlled by a P-P (Pneumatic-to-Pneumatic) proportional valve, the essential component to achieve weightless handling. After the clamp mode, the pilot pressure remains unchanged, because compressed air is completely closed by the two 2/2-way valves adjacent to the P-P valve. The P-P valve consists of three ports : an inlet port, an outlet port and a pilot port. The pilot port, connected to the air supply port of the air hoist, plays a role of sensing a feedback pressure, then the pressure of the outlet port is regulated to be the same as the pilot pressure as long as the inlet pressure is higher than the pilot pressure. Thus, the pressure of the air hoist, corresponding to the weight of the load, remains constant during the balance mode. The 3/2-way valve, controlling the direction of vertical motion of the air hoist, opens to connect the air line between the P-P valve and the air hoist in both the clamp mode and the balance mode. In the unclamp mode, the valve disconnects the air line so that compressed air is discharged from the air hoist.

In the pneumatic circuit, a pressure regulating valve is used. This valve is activated in the unclamp mode. The presetting pressure of the valve is previously determined in such a manner that the pressure should correspond to the weight of the jig without load. Thus, since unclamp mode, the balancing between the weight of the jig and the pressure of the air hoist is achieved.

The lower part of the figure, clamp/unclamp circuit, consists of a clamp valve, an unclamp valve, and a clamp cylinder. As explained earlier, a safety valve in unclamp is used for both guarantee of safe unload of materials and protection of abrupt ascending of the air hoist.

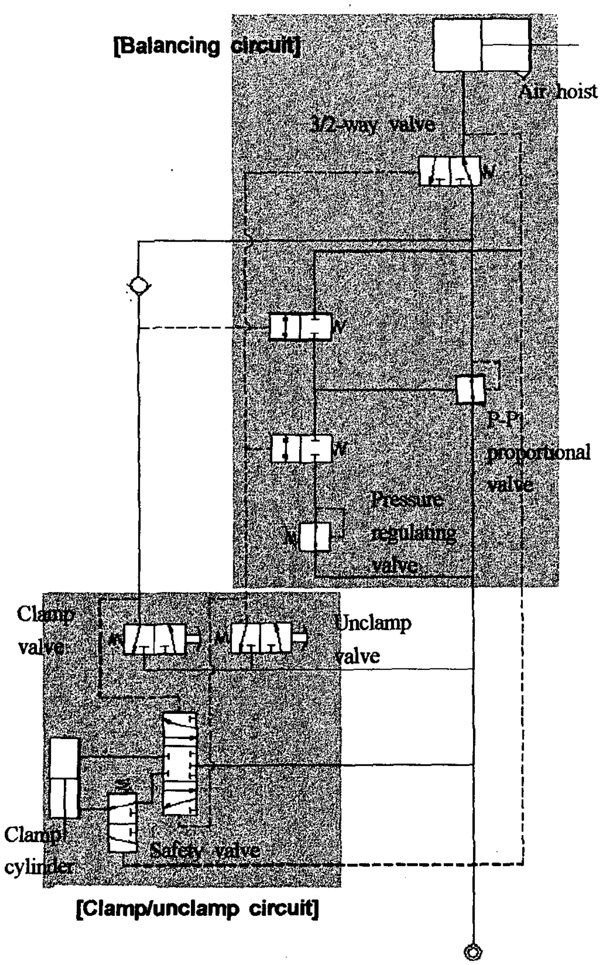


Fig. 4. Pneumatic control circuit for weightless control of the air hoist

3. Experiments

3.1 Experimental setup

To show the effectiveness of the proposed pneumatic circuit, a series of experiments are carried out for an air hoist. The maximum payload of the air hoist is 700N, and weights of load 100N to 500N are applied to the air hoist and control circuit. In this experiments, handling forces at various weights of load and the pressure change in the air hoist are examined.

The experimental setup is shown in Fig. 5. To obtain the data, the setup includes an encoder, ADC's (Analog-to-Digital Converters), amplifiers, pressure sensors, a force sensor, and a velocity sensor.

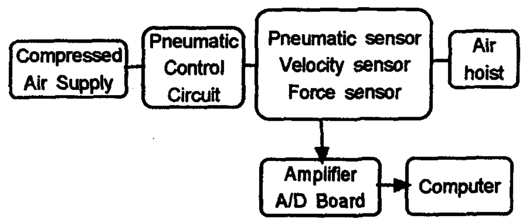


Fig. 5. Schematic diagram of the experimental setup.

3.2 Experiment results and discussions

Using the pneumatic circuit for weightless control of an air hoist, a series of experiments are carried out, and the results are described as follows:

3.2.1 Pressure for balancing of load

Firstly, the pressure range for balancing of various weights of load is examined. Thus obtained pressure range is applied to the initial setting of the pressure regulating valve, shown in Fig. 4. Fig.6 shows the pressure range obtained at each load. It can be seen from the figure that 1.2 to 2.4 bar should be required for balancing of 200N-weight load. The higher the load becomes, so does the pilot pressure. The range of the maximum pilot pressure and the minimum one comes from the nonlinearity of the system: friction of piston and cylinder, compressibility, valve nonlinearity, and so on. If pressure is set to high under a balancing range, the handling force for upward motion is lower than the one for downward motion, and vice versa.

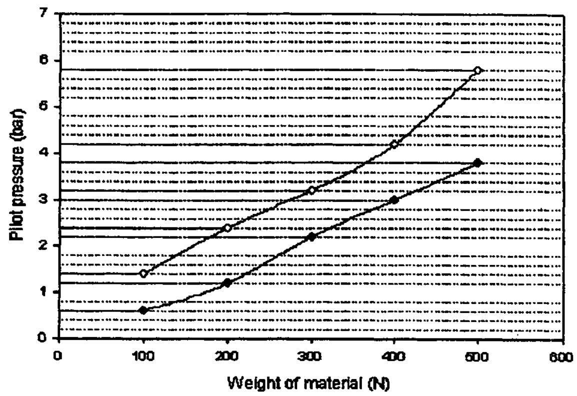
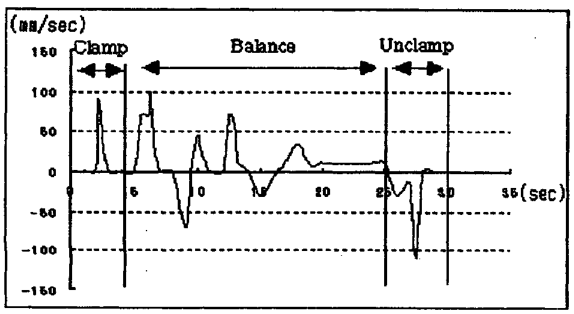


Fig. 6. Pilot pressure range for handling weights.

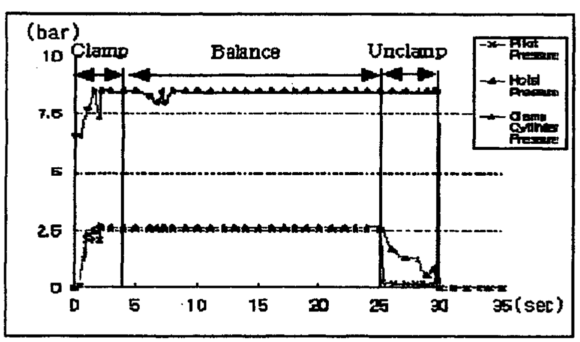
3.2.2 Pressure change in material handling

Using the pneumatic circuit thus designed, changes in pressure of the control circuit and air hoist for the various weights of load are examined with the load manually moving under three operation modes. The results for a low load of 200N are shown in Fig. 7(a) and 7(b); Fig. 7(a) shows the velocity change in handling of the load, while Fig. 7(b) shows the pressure changes under the velocity pattern. In the Figs 7(a) and 8(a), the positive velocity represents the ascending motion, while the negative one means the descending motion. The velocity pattern during the clamp mode and unclamp mode results from the related switch operation, while the pattern during the balance mode results from manual handling by the operator. The results for a high load of 400N are shown in Fig. 8(a) and 8(b); Fig. 8(a) shows the velocity change, and Fig. 8(b) shows the pressure changes.

The results shows that during the clamp operation the weight of load is memorized in terms of a pressure by the P-P proportional valve, as shown by the pilot pressure. The pilot pressure increases gradually during the clamp mode, and remains unchanged during the

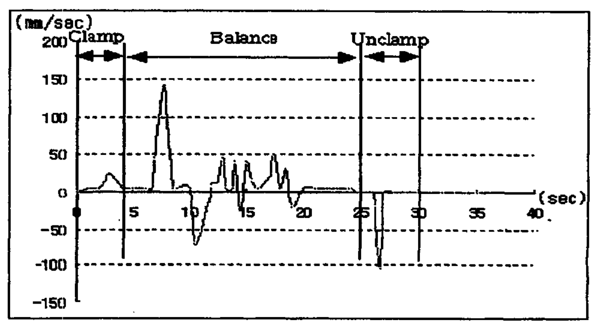


(a) Velocity pattern in handling of 200N load

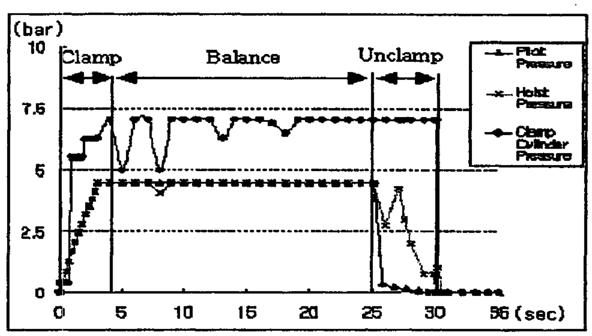


(b) Pressure changes

Fig. 7. The velocity profile and pressure changes for 200N weight in the pneumatic circuit



(a) Velocity pattern in handling of 400N load



(b) Pressure changes

Fig. 8. The velocity profile and pressure changes for 400N weight in the pneumatic circuit

Table 2. Material handling forces at each load

Load (N)		100	200	300	400	500
Handling force (N)	Min.	34	40	55	74	89
	Max.	50	70	95	114	125

balance mode. When the unclamp mode starts, the pilot pressure decreases rapidly. It can be seen that, during the clamp mode, the time for the pilot pressure to rise to steady state becomes long if the weight of load increases. Also, the higher the weight of load becomes, so does the pilot pressure.

During the balance mode, the pilot pressure is shown to remain constant, since the pilot pressure to the P-P valve is preserved from the start of the balance mode, as described in the previous section. However, the pressure of the clamp cylinder is momentarily decreased when the load is lifted. This is because air supply line is connected through the air hoist and the clamp cylinder.

The unclamp mode starts when the unclamp valve is operated. It can be seen that the pressure of the air hoist decreases gradually from the start of the unclamp mode. When the pressure of the air hoist drops to a low pressure, the pressure of the clamp cylinder becomes low immediately; When the air of the air hoist is completely discharged, unclamping starts. Accordingly the safety in unclamp operation is guaranteed.

3.2.3. Handling forces at various weights

During the balance mode, manual force is needed to lift and lower the load. Through experiment, the handling forces obtained are shown in Table 2. The table shows that the manual handling force is approximately proportional to the weight of load, and takes about 20 to 30 percent of the weight. The manual handling force results from the friction of the system.

It can be concluded from the experiments that the proposed pneumatic circuit can be used for air hoists in material handling with a small manual operation force. Also, the pneumatic circuit guarantees safety in unclamp operation.

4. Conclusion

This study proposed a pneumatic control circuit for air hoists to achieve weightless material handling. The pneumatic circuit memorizes the weight of material through feedback of pneumatic pressure in the air hoist. Such memory of the material weight is then used for achieving weightless material handling. With the proposed pneumatic circuit, weightless material handling is achieved through three operation modes: clamp mode, balancing mode, and unclamp mode. During the clamp mode, a material to be handled is fixed to a clamp jig, then the weight of load is memorized by a P-P proportional valve through feedback of the pressure in the air hoist. At balance mode, load can be lifted or lowered with small manual operation force. Unclamp operation can safely unload the material after examining sufficient discharge of compressed air from the air hoist

Through a series of experiments, handling forces and the response of the system for various material weights were examined. The results of the experiments show that the pneumatic control circuit can be used for air hoists in material handling with a small manual operation force.

Acknowledgement

This work was supported by the Korea Science and Engineering Foundation (KOSEF) through the Machine Tool Research Center at Changwon National University.

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